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Revision 0

Moisture-Monitoring Program at the Subsurface Disposal Area for Fiscal Year 2004

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October 2005

Idaho Cleanup Project

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ABSTRACT

This report discusses and summarizes moisture findings in the shallow surficial sediments and deep vadose zone from the Fiscal Year 2004 moisture-monitoring program at the Subsurface Disposal Area. The SDA is a radioactive waste landfill within the Radioactive Waste Management Complex at the Idaho National Laboratory Site. The data in this report will be used to increase confidence and reduce uncertainty in results from models of transport of contaminants to groundwater. These models support the remedial investigation and feasibility study for Waste Area Group 7, Operable Unit 7-13/14 and are part of the decision-making process to determine remedial actions for the SDA. These data can also be used to establish a baseline for post-remediation monitoring.

The results of the monitoring findings are discussed in the context of historical observations and monitoring. Results of waste-zone monitoring from advanced tensiometers (located at various depths outside the waste zone) and perched water level measurements are integrated with direct-push Type B tensiometers and soil-moisture, resistivity, and temperature sensors. This report compares and contrasts the characteristics of water movement through the waste zone and the surrounding undisturbed vadose zone; it also describes water movement through the deep vadose zone, especially near the interbeds.

The cyclical nature of precipitation and climate causes change in subsurface moisture, the effects of which can only be discovered through moisture monitoring. These effects will be crucial in terms of understanding the effectiveness of a potential future surface barrier.

EXECUTIVE SUMMARY

This report discusses, integrates, and summarizes moisture findings in the deep vadose zone (advanced tensiometer data) and shallow surficial sediments (probing project) from the Fiscal Year 2004 moisture-monitoring program at the Subsurface Disposal Area (SDA). The SDA is a radioactive waste landfill within the Radioactive Waste Management Complex at the Idaho National Laboratory Site. The data in this report will be used to increase confidence and reduce uncertainty in results from models of transport of contaminants to groundwater. These models support the remedial investigation and feasibility study for Waste Area Group 7, Operable Unit 7-13/14, and are part of the decision-making process to determine remedial actions for the SDA.

These data can also be used to establish a baseline for post-remediation monitoring. The cyclical nature of precipitation and climate causes change in subsurface moisture, the effects of which can only be discovered through moisture monitoring. These effects will be crucial in terms of understanding the effectiveness of final remediation actions.

The probing project was added as a "major change in scope" to replace coring in the *Second Revision to the Statement of Work for the Operable Unit 7-13/14 Waste Area Group 7 Comprehensive Remedial Investigation/Feasibility Study* by joint agreement of the Department of Energy-Idaho Operations Office, Idaho Department of Environmental Quality, and the Environmental Protection Agency. Moisture monitoring contributes to the following at the SDA:

- Establishing a baseline for remedial decision-making
- Demonstrating effectiveness of remedial action by comparing pre-remediation monitoring data to post-remediation data
- Identifying areas having relatively high soil moisture to promote runoff and reduce infiltration
- Estimating travel time for infiltrating water to reach interbeds and the Snake River Plain Aquifer to reduce uncertainty in infiltration modeling
- Identifying transport mechanisms and pathways that allow movement of water through basalt and through or around sedimentary interbeds
- Managing moisture through formulating policies for:
  - Snowmelt (to minimize infiltration into the Radioactive Waste Management Complex sediments and possible migration of contaminants)
  - Drainage of runoff and surface water (to prevent leaching from waste zones)
  - Avoiding promotion of rapid water movement into the waste zone (to avoid increasing contaminant transport)
- Providing information to help design effective remedial strategies.

Infiltration into the vadose zone is tied to surface water ponding in ditches, along roads, and in other low areas of the SDA. Though the SDA received only 62% of the long-term average precipitation in Fiscal Year 2004, moisture fronts moved through the surficial sediments under surface water-accumulation areas. Data from waste-zone monitoring (i.e., results from direct-push Type B

tensiometers and soil-moisture, resistivity, and temperature sensors integrated with results from advanced tensiometers located at various depths outside the waste zone and perched water level measurements from the vadose zone) indicate the following:

- Moisture increases in surficial sediment of the Depleted Uranium, High Plutonium Density, Moisture-Monitoring Network, Uranium/Enriched Uranium, and Activated Metal Focus Areas

- A long-term drying trend (i.e., decrease in water potential) below the surficial sediments in the basalt and interbed sediments, primarily along the east–west center axis of the SDA.

The greatest amount of drying overall occurred in the shallow basalts and in the 110-ft interbed, but drying also was observed at two locations in the 240-ft interbed. Data from the deep monitoring network indicate that the interior of the SDA currently is undergoing moisture drainage (downward flow by gravity), presumably due to decreased long-term infiltration caused by low precipitation during the past five years. Monitoring shows that the drought of the past five years has resulted in a measurable decrease in the amount of moisture in the geologic profile and the elimination of episodic pulses of water moving through the deep subsurface at these sites. Since a barrier cap would reduce infiltration and function as a localized "drought," placing a barrier cap over the SDA will reduce the movement of moisture and transport of contaminants. Continued monitoring will provide direct evidence of the effectiveness of the remedial action at the SDA.

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ACRONYMS

bls	below land surface
DPT	direct-push Type B tensiometer
FY	fiscal year
INL	Idaho National Laboratory
OU	operable unit
RWMC	Radioactive Waste Management Complex
SDA	Subsurface Disposal Area
SMR	soil-moisture, resistivity, and temperature

Moisture-Monitoring Program at the Subsurface Disposal Area for Fiscal Year 2004

1. INTRODUCTION

This report discusses, integrates, and summarizes moisture findings in the deep vadose zone (advanced tensiometer and perched water monitoring) and surficial sediments (probing project and perched water monitoring) from the Fiscal Year (FY) 2004 moisture-monitoring program at the Subsurface Disposal Area (SDA). The SDA is a radioactive waste landfill within the Radioactive Waste Management Complex (RWMC) at the Idaho National Laboratory (INL) Site (see Figure 1-1). The importance and utility of the probing project is underscored by its addition as a "major change in scope"[a] to replace coring in the *Second Revision to the Statement of Work for the Operable Unit 7 13/14 Waste Area Group 7 Comprehensive Remedial Investigation/Feasibility Study* (Holdren and Broomfield 2003). The data in this report will be used to increase confidence and reduce uncertainty in results from models of transport of contaminants to groundwater for the remedial investigation and baseline risk assessment for Waste Area Group (WAG) 7, Operable Unit (OU) 7-13/14.[b]

Previously, efforts to monitor the vadose zone and the waste zone (probing project) in the surficial sediments were separate projects. This report integrates these two projects into a single moisture-monitoring program. The purpose of these projects was to characterize the hydrological setting at these sites. The cyclical nature of precipitation and climate causes change in subsurface moisture, the effects of which can only be known through moisture monitoring. These effects will be crucial in terms of verifying the effectiveness of final remediation actions. Understanding the mechanics and timing of water movement through soil, waste, and the underlying subsurface provides opportunities to manage surface water more efficiently and effectively in order to minimize leaching and transport of contaminants to the Snake River Plain Aquifer. Moisture monitoring contributes to the following at the SDA:

- Establishing a baseline for remedial decision-making
- Demonstrating effectiveness of remedial action by comparing pre-remediation monitoring data to post-remediation data
- Identifying areas having relatively high soil moisture to promote runoff and reduce infiltration
- Estimating travel time for infiltrating water to reach interbeds and the Snake River Plain Aquifer to reduce uncertainty in infiltration modeling
- Identifying transport mechanisms and pathways that allow movement of water through basalt and through or around sedimentary interbeds

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a. This change was by joint agreement of the Department of Energy Idaho Operations Office, the Idaho Department of Environmental Quality, and the Environmental Protection Agency in accordance with the *Federal Facility Agreement and Consent Order* (DOE-ID 1991) and "Replace[d] coring through waste with installation and monitoring of Type A and Type B probes and with materials retrieved from Pit 9 by the OU 7-10 Glovebox Excavator Method Project" (Holdren and Broomfield 2003).

b. The *Federal Facility Agreement and Consent Order* lists 10 WAGs for INL. Each WAG is subdivided into OUs. The RWMC is identified as WAG 7 and originally contained 14 OUs. Operable Unit 7-13 (transuranic pits and trenches remedial investigation and feasibility study) and OU 7-14 (WAG 7 comprehensive remedial investigation and feasibility study) were ultimately combined into the OU 7-13/14 comprehensive remedial investigation and feasibility study for WAG 7.

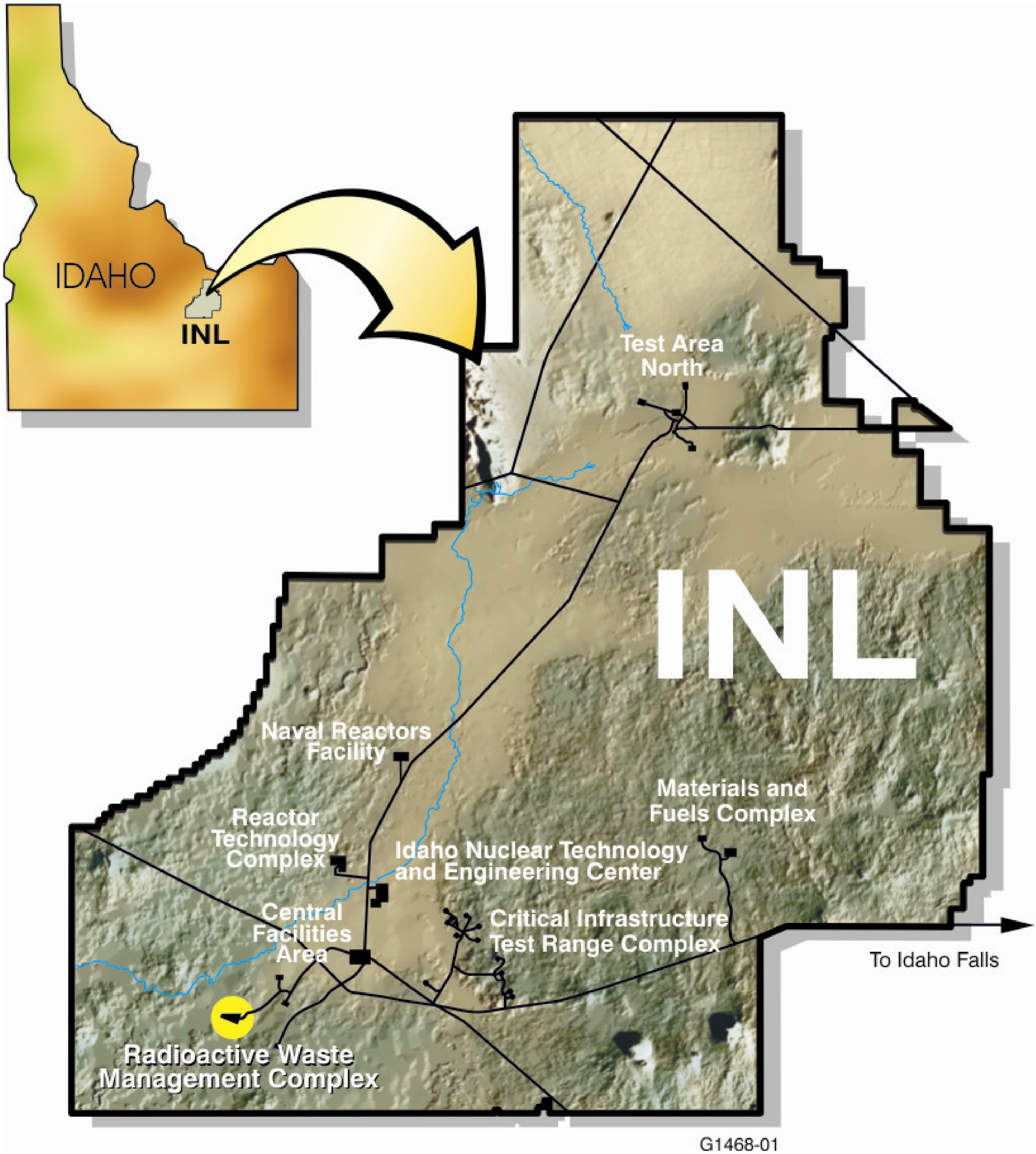

Figure 1-1. Graphic showing the location of the Radioactive Waste Management Complex at the Idaho National Laboratory Site.

- Managing moisture through formulating policies for:

  - Snowmelt (to minimize infiltration into RWMC sediments and possible migration of contaminants)

  - Drainage of runoff and surface water (to prevent leaching from waste zones)

  - Avoiding promotion of rapid water movement into the waste zone (to avoid increasing contaminant transport)

- Providing information to help design effective remedial strategies.

An overall understanding of moisture increases, decreases, and movement is vital to manage waste buried at the SDA in a responsible manner and to verify successful long-term remediation. For example, monitoring shows that the drought of the past five years has resulted in a measurable decrease in the amount of moisture in the geologic profile and the elimination of episodic pulses of water moving through the deep subsurface at these sites. Since a barrier cap would reduce infiltration and function as a localized "drought," placing a barrier cap over the SDA will reduce the movement of moisture and transport of contaminants. Continued monitoring will provide direct evidence of the effectiveness of the remedial action at the SDA.

1.1 Purpose

Data from the soil-moisture monitoring program reported in this document are used to increase confidence and reduce uncertainty in results from models of contaminant transport to groundwater. These models support the remedial investigation and feasibility study for OU 7-13/14 and are part of the decision-making process to select the most effective remedial actions for the SDA. These data from the monitoring program also increase understanding of baseline conditions at the SDA, which will help determine the effectiveness of remedial actions chosen in the record of decision.

1.2 Scope

This document reports results of FY 2004 monitoring of waste zone and vadose zone soil moisture at the SDA. Results of waste-zone monitoring from advanced tensiometers (located at various depths outside the waste zones) and perched water measurements are integrated with results from direct-push Type B tensiometers (DPTs) and soil moisture, resistivity, and temperature (SMR) sensors.

1.3 Overview

Reliably predicting contaminant flow and transport in the vadose zone is difficult because of the large depth to groundwater (178.3 m [585 ft]); the presence of a heterogeneous mixture of primarily fractured rock (95%) and thin layers of sediments (5%); a history of episodic infiltration events; and the form, type, disposal practices, waste distribution, and volumes of waste buried in the SDA. The potential long-term monitoring approach is to focus primarily in the surficial sediments and interbeds to obtain data over laterally extensive media, then target areas where moisture has been observed, such as perched water detected in the basalt or at the surficial sediment-basalt contact. The monitoring should emphasize the surficial sediments for short time-scale, smaller physical-scale measurements and obtaining data at greater depths to provide longer time-scale, larger physical-scale trending data. Advanced tensiometers were developed for use in the deep vadose zone. A network of these instruments was installed in the vadose zone beneath and adjacent to the SDA, at depths ranging from 2.7 to 117 m (9 to 385 ft) below land surface. From 1997 through 2003, 67 advanced tensiometers and 337 drive probes were installed in the SDA to collect monitoring data directly from the deep vadose and the waste zones. Unlike any monitoring equipment previously deployed in the SDA, drive probes can penetrate into buried waste to provide direct or immediately proximal monitoring capabilities (Holdren et al. 2002). These tensiometers and drive probes were installed to monitor infiltration, distribution, and drainage of water under saturated or unsaturated conditions. Monitoring the network supported the decision process for OU 7-13/14 (Holdren et al. 2002) and the following specific objectives:

- Assess the current conceptual model of water transport in the unsaturated zone beneath RWMC
- Provide field-scale data for hydrologic model calibration and prediction
- Define baseline soil-water conditions within sedimentary interbeds and basalts beneath RWMC environs before the system is affected by remedial action for the following purposes:
  - Developing a baseline description of the water potential in the area
  - Determining long-term status of the water potential beneath the buried waste
  - Detecting and monitoring movement of wetting fronts to the instrumented depths
  - Calculating limits for local net infiltration rates
- Detect optimal timing for lysimeter sampling by sensing the presence of soil moisture
- Assess lateral movement of water from the spreading areas in conjunction with planned tracer tests
- Define baseline soil-water conditions within surficial sediments and the waste zone
- Define moisture conditions within the waste zones
- Identify the timing and relative magnitude of moisture events
- Define the presence and extent of any saturated conditions (Salomon 2004, Meyer et al. 2005).

The goal for monitoring the vadose zone ultimately is to protect the Snake River Plain Aquifer, a sole source aquifer (56 FR 50634 1991). The aquifer supplies drinking water for many communities in southeastern Idaho and irrigation water to agriculture.

Moisture-monitoring activities in the SDA will be used to decrease the uncertainty in flow and transport predictions and allow direct evidence of changes in the vadose zone that influence these predictions. Long-term follow-on monitoring of moisture will also allow verifying the effectiveness of final remedial action and provide performance data to site engineers and reassurance to regulators and stakeholders.

1.4 Brief History and Description of the Subsurface Disposal Area

Originally established in 1949 as the National Reactor Testing Station, the INL Site is a Department of Energy-managed reservation, occupying 2,305 km^2 (890 mi^2) in the northeastern region of the Snake River Plain. The INL Site extends nearly 63 km (39 mi) from north to south, is about 58 km (36 mi) wide in its broadest southern portion, and occupies parts of five southeast Idaho counties (Holdren et al. 2002).

Located in the southwestern quadrant of the INL Site, RWMC encompasses a total of 72 ha (177 acres) and is divided into three separate areas by function: the SDA, the Transuranic Storage Area, and the administration and operations area. The current size of the SDA is 39 ha (97 acres). Located adjacent to the east side of the SDA, the Transuranic Storage Area was added to RWMC in 1970, encompasses 23 ha (58 acres), and is used to store, prepare, and ship retrievable transuranic waste to the Waste Isolation Pilot Plant. The 9-ha (22-acre) administration and operations area at RWMC includes administrative offices, maintenance buildings, equipment storage, and miscellaneous support facilities (Holdren et al. 2002). See Figure 1-2 for a map of the SDA showing the location of waste disposal areas.

The SDA is a radioactive waste landfill with shallow subsurface disposal units consisting of pits, trenches, and soil vaults. Contaminants in the landfill include hazardous chemicals, remote-handled fission and activation products, and transuranic radionuclides. Waste acceptance criteria and record-keeping protocols for the facility have changed over time in keeping with waste management technology and legal requirements. Today’s requirements are much more stringent as a result of knowledge developed over the past several decades about potential environmental effects of waste management techniques. Previously, however, shallow landfill disposal of radioactive and hazardous waste was the conventional disposal technology.

Construction, operation, and decommissioning of INL nuclear reactor testing programs have resulted in large volumes of waste. Various containers were used in shipping and disposing of the waste, including steel drums (30-, 40-, and 55-gal), casks, cardboard cartons, and wooden boxes (as large as 105 × 105 × 214 in.). Larger individual items—such as tanks, furniture, process and laboratory equipment, engines, and vehicles—were placed separately as loose trash. Additionally, liquid waste was disposed of in the SDA, including direct disposal of free liquids to the pits and trenches and disposal of solidified liquids in containers.

Radioactive waste from off-INL sources originated from a variety of facilities, including military and other defense agencies, universities, commercial operations, and the Atomic Energy Commission. The primary off-INL contributor was the Rocky Flats Plant. Shipping of waste to INL from the Rocky Flats Plant began in April 1954 and continued into late 1989. Waste from the Rocky Flats Plant was deposited underground in a series of pits and trenches until 1970, when the U.S. Atomic Energy Commission policy was implemented requiring segregation and retrievable storage of all solid transuranic waste. After 1970, transuranic waste received from the Rocky Flats Plant was placed in aboveground, earthen-covered retrievable storage. The aboveground stored waste was designated as transuranic retrievable waste (Vejvoda 2005). Initially, waste was stacked in pits and trenches. However, beginning in 1963, some waste was dumped to reduce labor costs and minimize radiation exposure of personnel. Current disposal operations stack contact-handled waste to maximize disposal capacity of the landfill. Remote-handled waste is placed in either concrete vaults or the bulk storage area.

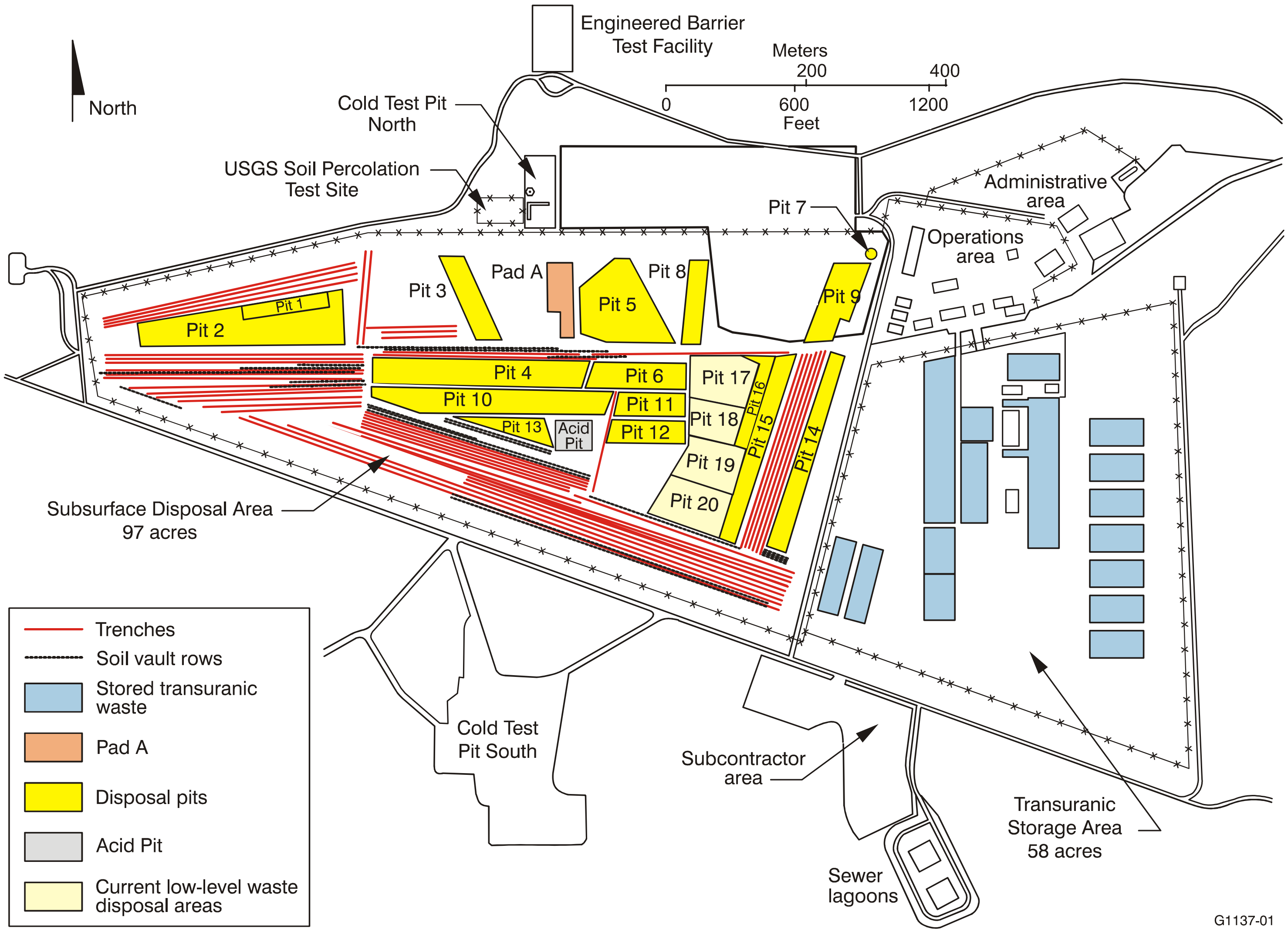

Figure 1-2. Map of the Radioactive Waste Management Complex showing pits, trenches, and soil vault rows within the Subsurface Disposal Area.

1.5 Document Organization

The remaining sections in this document address the following topics:

- Section 2 describes the physical setting of RWMC, including topography, climatology, and geology.

- Section 3 describes the probes and tensiometers used in the moisture-monitoring program and presents an overview of the monitoring activities at RWMC.

- Section 4 discusses results of advanced tensiometer monitoring in the deep vadose zone for FY 2004.

- Section 5 presents results of perched water monitoring for FY 2004.

- Section 6 presents results of surficial sediment monitoring for FY 2004.

- Section 7 discusses the results of FY 2004 monitoring and incorporates them into the evolving understanding of vadose zone moisture movement at the SDA to indicate the purpose for continued monitoring.

- Sections 8, 9, and 10 present the conclusions, summary, and recommendations for the shallow surficial sediment moisture-monitoring network, the deep moisture-monitoring network, and monitoring the aquifer.

- Section 11 provides complete references for information sources cited throughout the document.

- Appendix A contains data plots for SMR sensors.

- Appendix B contains data plots and tabular information for DPTs.

- Appendix C contains a detail of water level in selected neutron access tubes.

- Appendix D contains comparisons of temperature corrected and nontemperature-corrected data from SMRs.

2. PHYSICAL SETTING

This section gives a brief introduction to the topography, climatology, and geologic setting of the SDA and surrounding vicinity. These features play an important role in the quantities and behavior of infiltrating water:

- The topography can cause surface runoff to collect and focus infiltration.
- Climatology determines the amounts of water available for infiltration.
- Subsurface geology can control infiltration rates by providing barriers or conduits.

2.1 Topography

The RWMC lies within a natural topographic depression (illustrated in Figure 2-1). Localized runoff from the surrounding topography is prevented from entering the SDA by the perimeter drainage channel and dike, which is about 0.6 to 4.5 m (2 to 15 ft) higher than areas within the SDA. The perimeter drainage channel around the SDA conveys surface runoff from external areas west, south, and north of the SDA to a point east of the SDA, where it enters the main drainage channel along Adams Boulevard. A storm water drainage detention basin is also located on the east end of the SDA. This collects runoff from the interior areas of the SDA for sampling before the water is pumped to the discharge culverts into the main drainage channel. The main channel drains to the surrounding desert northeast of RWMC where the surface water readily infiltrates or evaporates. A second dike within the SDA was constructed around the active low-level waste disposal area located in the eastern part of the SDA.

2.2 Climatology

Meteorological and climatological data for RWMC are collected and compiled from a meteorological station at RWMC operated by the National Oceanic and Atmospheric Administration field office since 1993. However, the National Oceanic and Atmospheric Administration meteorological station located at the Central Facilities Area has been in operation longer than the RWMC station and has a more complete database. As a result, data collected from the Central Facilities Area meteorological station are used in this report to describe meteorological conditions in the SDA.

The region in which the INL Site is located is classified as arid to semiarid. The 50-year (i.e., 1953 to 2003) average annual precipitation at the INL Site is 22.1 cm (8.7 in.). The rates of precipitation are highest during May and June and the lowest in July. Normal winter snowfall occurs from November through April, though occasional snowstorms occur in May, June, and October. Snowfall at the INL Site ranges from a low of about 17.3 cm (6.8 in.) per year to a high of about 151.6 cm (59.7 in.) per year, and the annual average is 70.1 cm (27.6 in.) (Clawson, Start, and Ricks 1989). Figure 2-2 provides time-series plots of monthly precipitation recorded at the National Oceanic and Atmospheric Administration field station at Central Facilities Area for recent years. Data were obtained by summarizing the daily data obtained from the Interactive Numeric and Spatial Information Data Engine website.[c] The average annual INL Site precipitation rate of 22.1 cm (8.7 in.) corresponds to a monthly average of 1.84 cm (0.73 in.). This average is shown as a horizontal line in Figure 2-2.

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c. URL: http://www.insideidaho.org/asp/dates.asp?stations=104460.

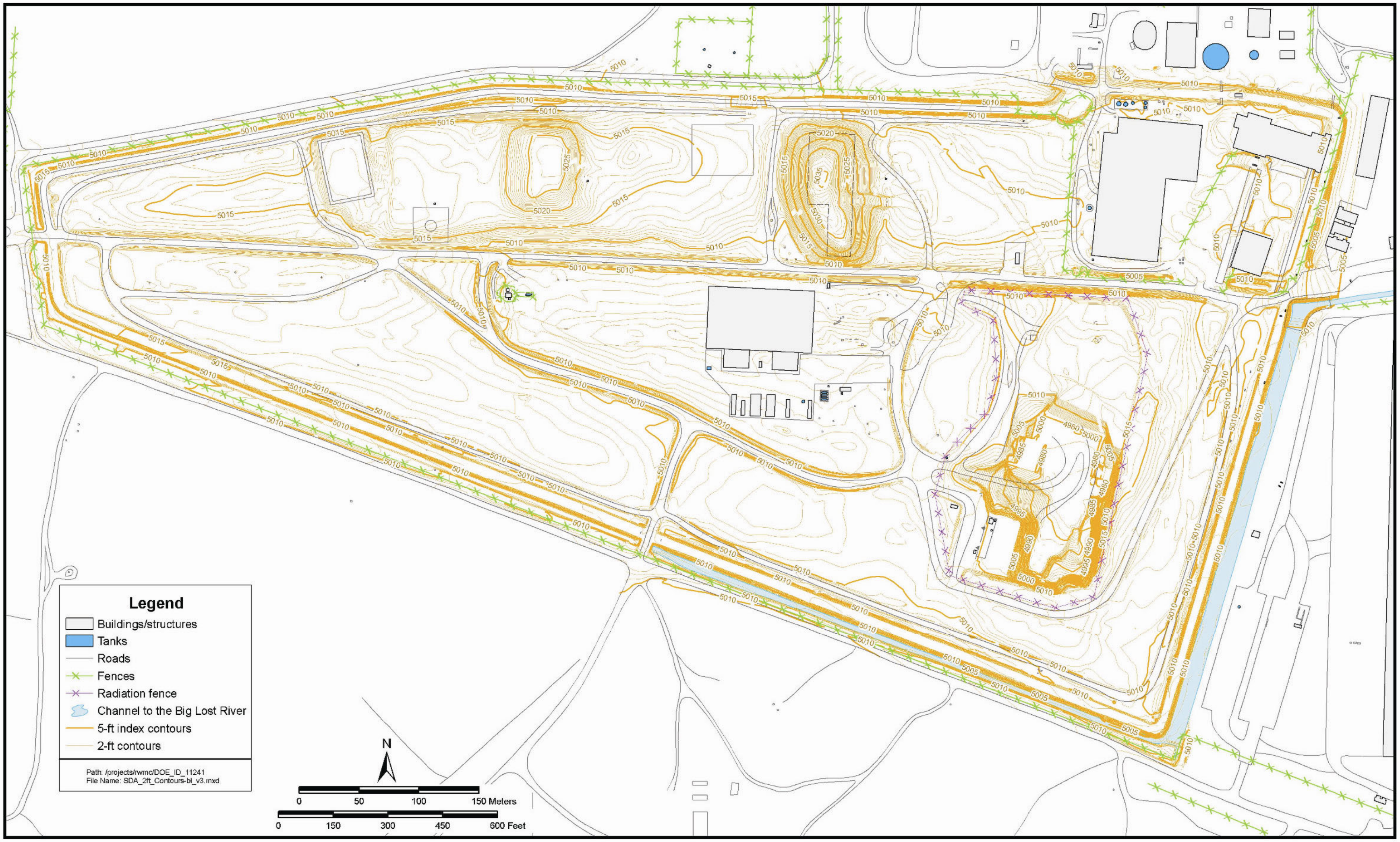


Figure 2-1. Topographic map of the Subsurface Disposal Area.

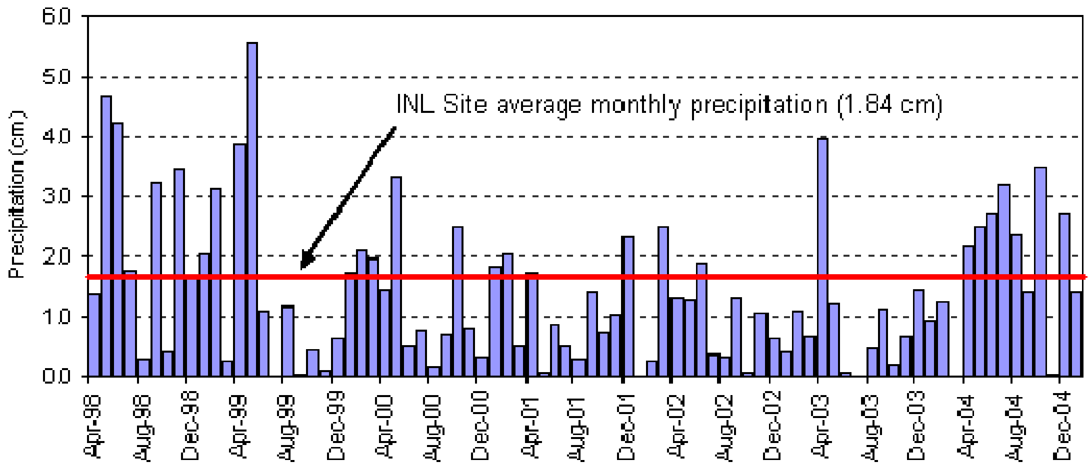


Figure 2-2. Bar graph of monthly precipitation recorded at the Central Facilities Area weather station and used to describe meteorological conditions at the Subsurface Disposal Area. Average monthly precipitation for the Idaho National Laboratory Site is shown as a horizontal line.

Drought is a normal, recurring climate event, occurring almost everywhere and varying from region to region. There is no consensus among scientists, water users, and other stakeholders as to the exact definition of a drought. The definition is relative to an area's long-term average precipitation. A drought can be defined as an extensive period of below-average rainfall. Figure 2-2 shows that drought conditions have persisted in this area since mid- to late-1999. Only 10 months out of the 57-month period from June 1999 to March 2004 (about 17%) received greater than average precipitation. The average monthly precipitation during this period was 1.0 cm (0.4 in.), nearly one-half of the long-term monthly average. However, the drought was somewhat relieved by seven months of above-average monthly precipitation in 2004.

Other parameters affecting water availability are temperature, humidity, and evapotranspiration. At the INL Site in general, there is a wide diurnal range of temperature near the ground. The average summer daytime maximum temperature is 28°C (83°F), while the average winter daytime maximum temperature is –0.6°C (31°F). During a 38-year period of meteorological records (i.e., 1950 through 1988) from the Central Facilities Area, temperature extremes at the INL Site have varied from a low of –44°C (–47°F) in January to a high of 38°C (101°F) in July (Clawson, Start, and Ricks 1989). The average relative humidity at the INL Site ranges from a monthly average minimum of 18% during the summer months to a monthly average maximum of 55% in the winter (Clawson, Start, and Ricks 1989).

The potential annual evaporation from saturated ground surface at the INL Site is approximately 109 cm (43 in.) with a range of 102 to 117 cm (40 to 46 in.) (Clawson, Start, and Ricks 1989). About 80% of this evaporation occurs between May and October. During the warmest month, July, the potential daily evaporation rate is approximately 0.63 cm/day (0.25 in./day). During the coldest months, December through February, evaporation is low and may be insignificant. Surface winds can strongly affect potential evaporation. Local mountain valley features exhibit a strong influence on the wind flow under other meteorological conditions as well. The average midspring windspeed recorded at the Central Facilities Area meteorological station at 6 m (20 ft) was 15 kph (9.3 mph), while the average midwinter windspeed recorded at the same location was 8.2 kph (5.1 mph) (Irving 1993).

2.3 Geology

Figure 2-3 illustrates the geology at RWMC. Anderson and Lewis (1989) defined 10 basalt flow groups and seven major sedimentary interbeds underlying RWMC. Basalt flows at RWMC are typical eastern Snake River Plain basalts and occur as layered flow groups. Anderson and Lewis (1989) report a maximum measured flow thickness of 12.2 m (40 ft) with averages ranging from 1.5 to 5.2 m (5 to 17 ft). Using Anderson and Lewis (1989) nomenclature, the interbeds are called A-B, B-C, and C-D sedimentary layers, so named for the basalt flow groups (i.e., A, B, C, and D) that bound the layers above and below. Interbeds consist of generally unconsolidated sediments, cinders, and breccia. The three uppermost sedimentary layers also are commonly referred to as 9-, 34-, and 73-m (30-, 110-, and 240-ft) interbeds. The C-D interbed is by far the most continuous. However, each interbed contains known gaps. The A-B interbed is very discontinuous and generally is beneath only the northern half of the SDA. A comprehensive examination of the lithologic characteristics beneath the SDA can be found in Leecaster (2004).

The surficial sediments at RWMC range in thickness from 0.6 to 7.0 m (2 to 23 ft) and consist primarily of fine-grained playa and alluvial material (Kuntz et al. 1994). Surficial sediments are classified as a silty loam and are typically fine-grained silts and clays. Irregularities in soil thickness generally reflect the undulating surface of underlying basalt flows. Many physical features are common within the soil stratigraphy of the RWMC area, such as pebble layers, freeze-thaw textures, glacial loess deposits, and platy caliche horizons. Surface soil in RWMC has been significantly disturbed and recontoured with additional backfill added for control of subsidence and runoff. Fill brought into the SDA to increase cover thickness came from the spreading areas and consisted of silty loam or silty clayey loam (Tullis et al. 1993). The sediment supports a variety of native vegetation—most notably crested wheat grass. Generally, the soil has moderate water-holding capacity, though some areas of RWMC have shallow soil with low water-holding capacity (Bowman et al. 1984).

Precipitation that falls on the SDA in the form of snow has the greatest impact on subsurface moisture conditions, especially if it falls over frozen ground (Bishop 1998). When the snow melts, the meltwater flows to low areas (e.g., ditches along the roads and ponds) until the ground under the ponds thaws and permits infiltration. This scenario focuses infiltration into the vadose zone and maximizes the amount of water available for contaminant leaching and transport in those areas.

Findings by Hull and Bishop (2003), Koeppen et al. (2005), and McElroy (1993) all suggest the following two points:

- Infiltration of ponded surface water—from snowmelt and rainfall—is key to transport and can increase transport times by orders of magnitude

- Transport time of a conservative tracer (i.e., moves with water) from land surface to the aquifer inside the SDA is less than 20 years (including several years of severe drought).

The Snake River Plain Aquifer lies approximately 180 to 197 m (590 to 610 ft) below the RWMC land surface (Wood and Wylie 1991). The level of the water table and flow rates fluctuate in association with long-term meteorological conditions, seasonal recharge, and the volume of surface water discharge to the spreading areas. Groundwater levels measured in June 2004, for aquifer wells in RWMC and upgradient areas, are shown as contour lines of equal elevation in Figure 2-4. Hydrographs of recent water table conditions are provided in Figure 2-5 for several RWMC-vicinity wells.

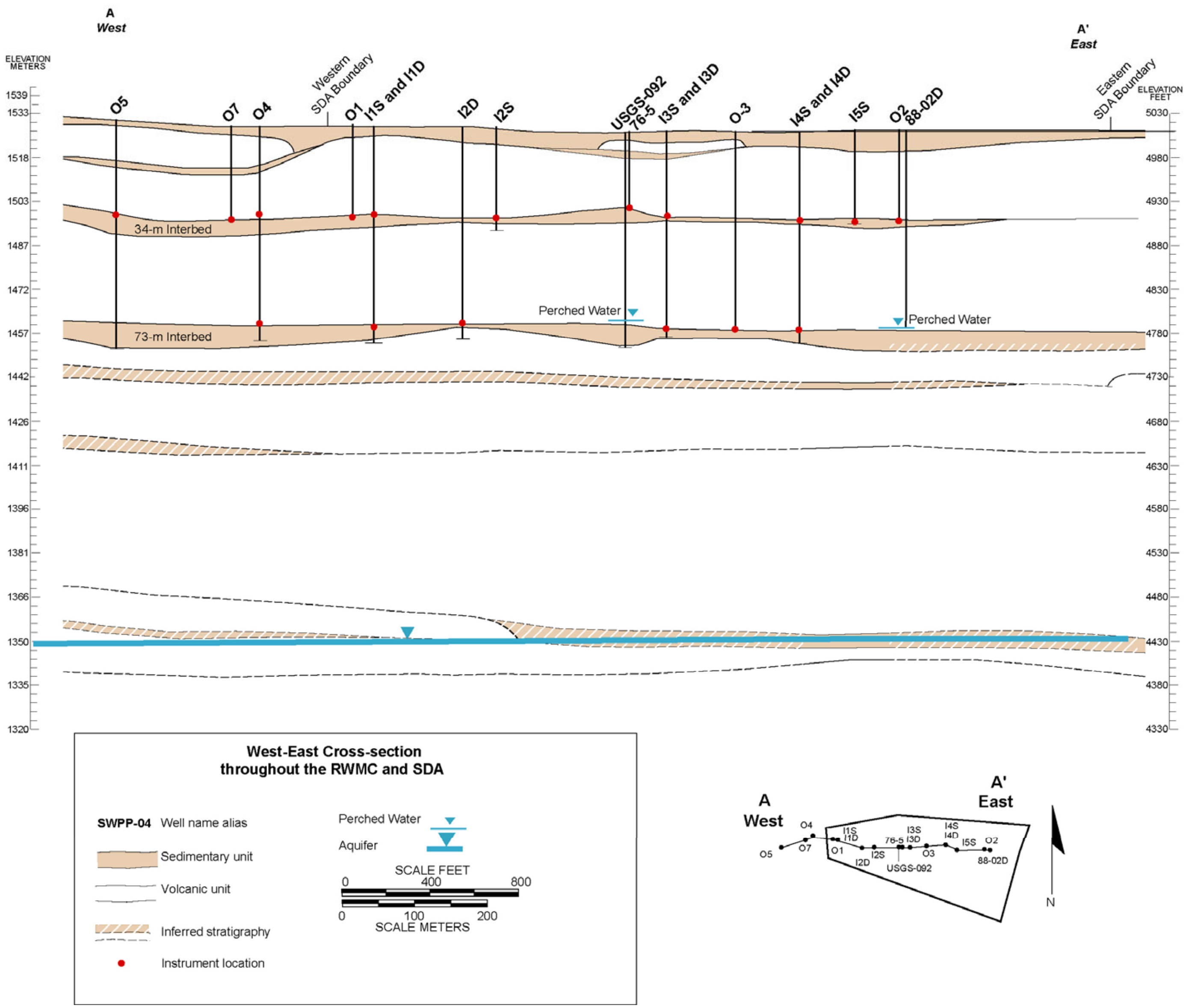


Figure 2-3. Geologic cross section in the Radioactive Waste Management Complex vicinity.

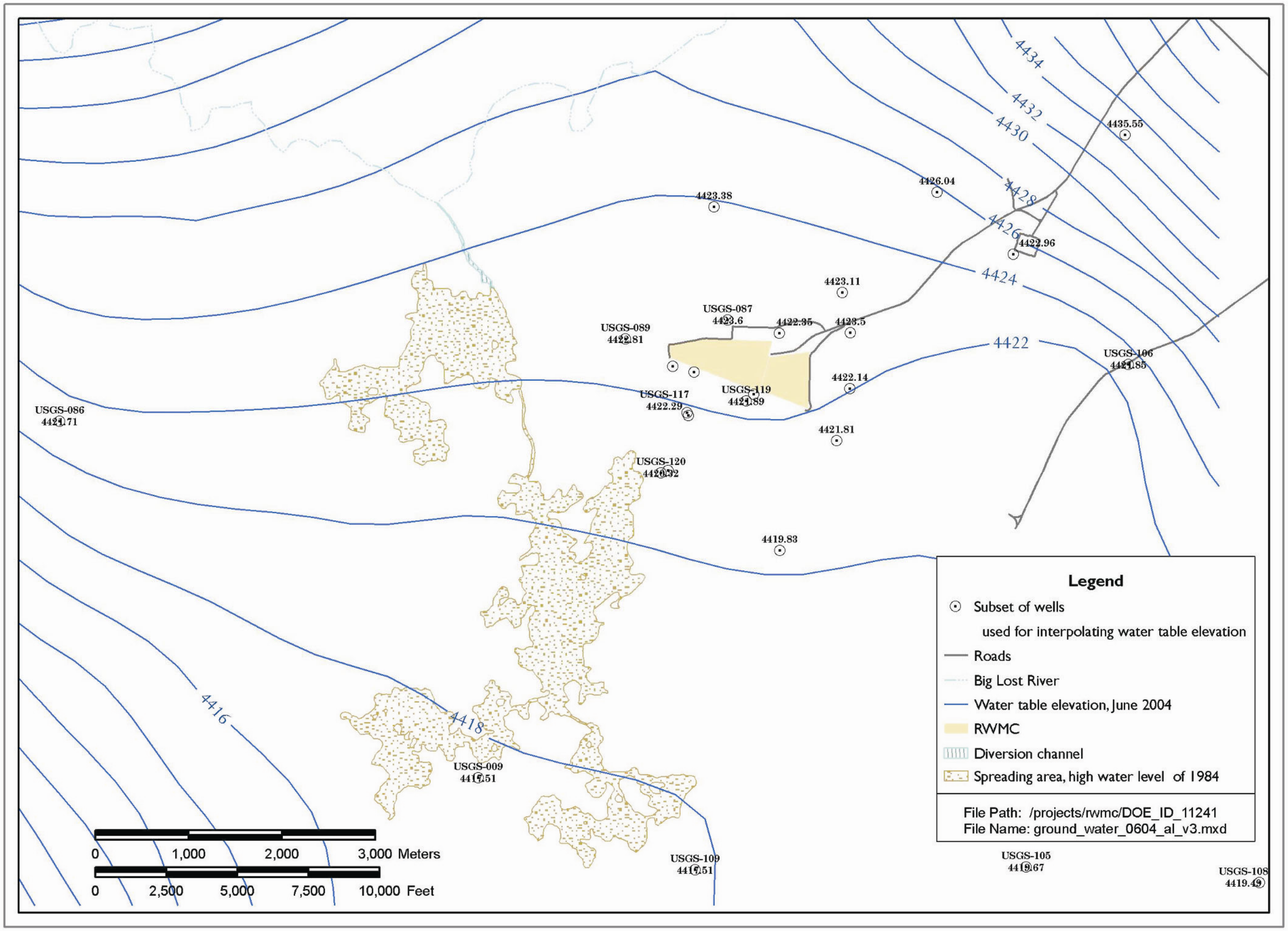


Figure 2-4. Water table contours (2-ft contour intervals; feet above mean sea level) measured in the aquifer in June 2004 near the Radioactive Waste Management Complex.

The RWMC is highlighted in Figure 2-4. The water table elevations from the wells used in making Figure 2-4 are posted on the figure. Also shown are the names of the wells that appear in Figure 2-5.

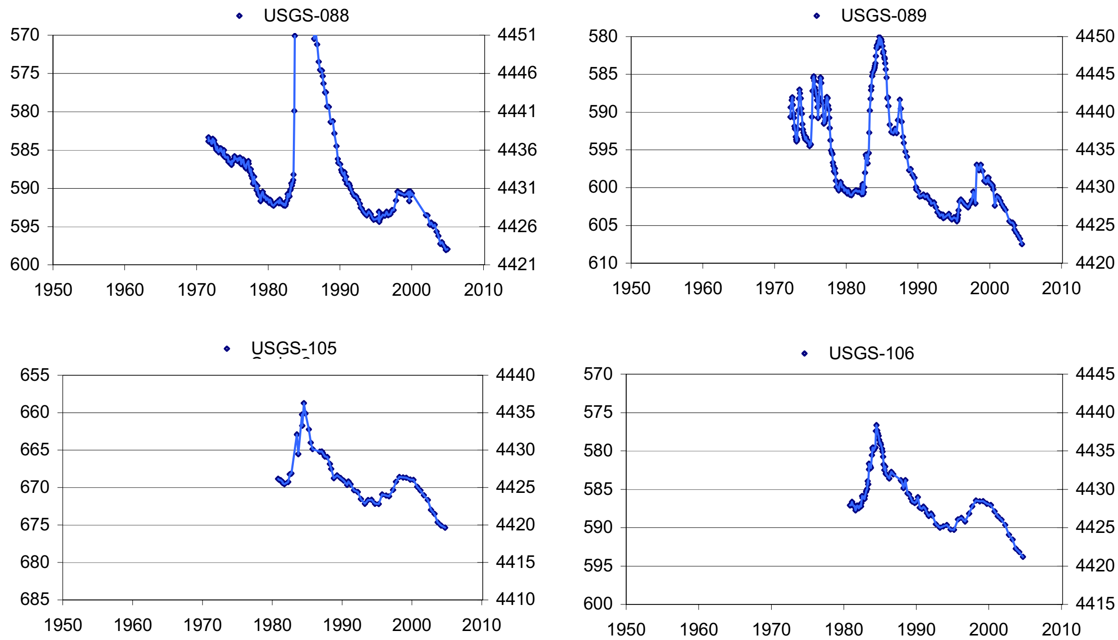


Figure 2-5. Hydrographs of water table elevation for several Radioactive Waste Management Complex aquifer wells (depth to water [ft], left axis; water table elevation [ft above mean sea level], right axis).

As with many aquifer wells, water levels below RWMC have been declining over the last few years. This is likely to be the result of decreased recharge due to prolonged regional drought conditions and changes in irrigation practices. Specific to RWMC-vicinity aquifer wells, rates of water table decline have been about 0.6 to 0.9 m/year (2 to 3 ft/year) for the past three years. These are listed in Table 2-1. The hydrographs of the four aquifer wells in Figure 2-5 all exhibit this decline occurring over the last three years.

The observed patterns of declining water levels may be the result of prolonged drought conditions affecting recharge in the regional highland recharge areas that include the Yellowstone Plateau to the northeast, and Lost River, Lemhi, and Beaverhead mountain ranges to the north and northwest. Continued frequent monitoring of RWMC-vicinity aquifer wells, as well as deeper perched water wells near the spreading areas and near the SDA, will provide an opportunity to determine the effects of local recharge, especially if the region is returning from drought conditions.

Table 2-1. Annual rate of water table decline in 2004 for several Radioactive Waste Management Complex aquifer wells.

Well Name	Well Identification Number	2004 Water Table Rate of Decline (ft/yr)
M4D	767	1.90
M6S	768	3.52
RWMC-MON-A-013	906	1.86

Table 2-1. (continued).

Well Name	Well Identification Number	2004 Water Table Rate of Decline (ft/yr)
USGS-009	458	1.53
USGS-086	535	2.10
USGS-088	537	2.17
USGS-089	538	2.22
USGS-105	554	1.19
USGS-106	555	1.55
USGS-109	558	1.70
USGS-120	569	1.19

3. OVERVIEW OF MOISTURE-MONITORING SENSORS

Four types of instruments have been used to monitor moisture at the SDA. Table 3-1 shows the four types of instruments, sampling frequency, depths monitored below land surface, and type of data obtained by each type of instrument (Meyer et al. 2005).

Table 3-1. Types of data collected for the moisture-monitoring program.

Instrument Type	Sampling Frequency	Vadose Zone Location	Type of Data Obtained
1. Advanced tensiometer	2 to 4-hour	Deep (16 to 385 ft) in and surrounding the Subsurface Disposal Area	Water potential (centimeters of water)
2. Water level (perched) transducer and datalogger	Hourly	Shallow and deep in the Subsurface Disposal Area (10 to 220 ft)	Presence of water and water level (centimeters of water)
3. Soil-moisture, resistivity, and temperature	2-hour	Surficial sediments in the Subsurface Disposal Area (less than 25 ft)	Moisture content (percent by volume), resistivity (ohm-meters), temperature (^{o}C)
4. Direct-push Type B tensiometer	2-hour	Surficial sediments in the Subsurface Disposal Area (less than 25 ft)	Water potential (centimeters of water)

Figures 3-1 through 3-4 show the four sensor types that comprise the moisture-monitoring network.

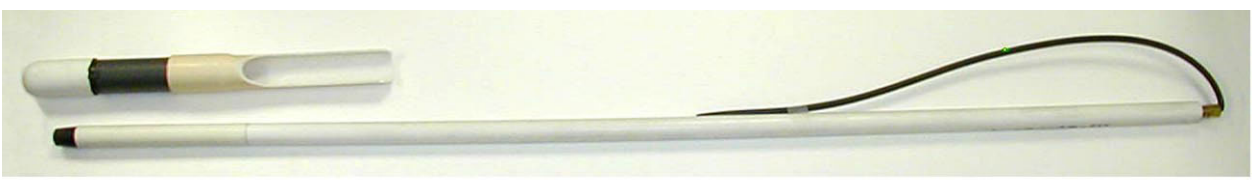


Figure 3-1. Advanced tensiometer.

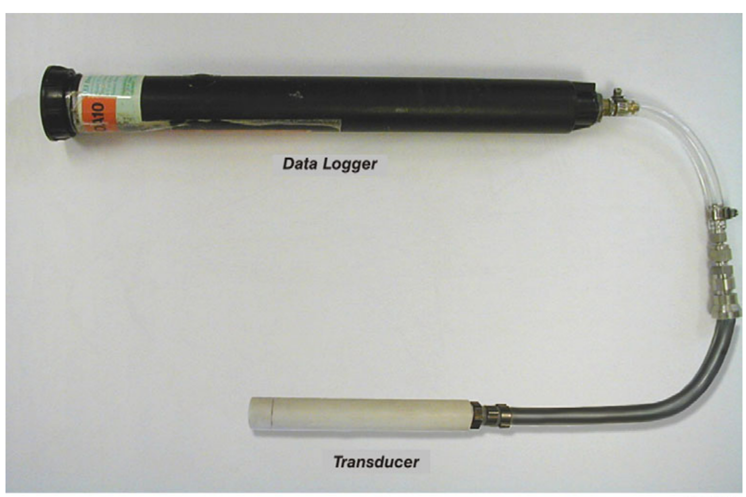


Figure 3-2. Water level transducer and datalogger.

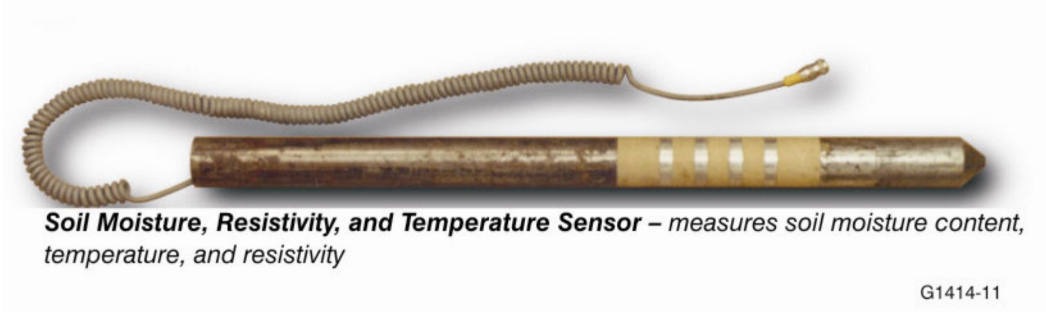


Figure 3-3. Soil-moisture, temperature, and resistivity sensor.

Figure 3-4. Direct-push Type B tensiometer.

3.1 Advanced Tensiometers and Perched Water Monitoring

Advanced tensiometers are instruments that measure the relative energy status of water, referred to as water potential. Tensiometers can measure either saturated or unsaturated conditions. Water potential describes how tightly water is held to rock or sediment by capillary and adsorptive forces. When combined with elevation head, it describes the total head (pressure) used in flow equations to evaluate the movement of water in the unsaturated zone. Under fully saturated conditions, water is at hydrostatic pressures greater than atmospheric pressure, and water potential can be considered positive. In the unsaturated state, water potential is considered to be negative, by convention, because the hydrostatic pressures are less than atmospheric pressures. The advanced tensiometer pressure measurements are expressed in terms of an equivalent head of water (e.g., centimeters of water).

The advanced tensiometer (see Figure 3-1) is composed of a porous cup (i.e., 1 bar, standard flow, ceramic, 50 to 60 ml volume) installed at a specified depth with an attached polyvinyl chloride pipe (i.e., Class 200, 2.54 to 3.81 cm [1 to 1.5 in.]) that extends to land surface. A volume of water is placed in the polyvinyl chloride pipe to fill the porous cup. A pressure transducer is placed inside the polyvinyl chloride pipe and seated adjacent to a tapered surface above the porous cup by means of a rubber stopper, sealing the water (i.e., lower) chamber in the porous cup from the water in the polyvinyl chloride pipe (i.e., upper water chamber). The water in the porous cup will move into or out of the formation until the pressure in the cup is equal to the water pressure in the surrounding soil. The pressure transducer measurement of this partial vacuum is a direct measure of the soil-water potential. The advanced tensiometer design permits water-potential measurements at any depth due to placement of the pressure sensor immediately adjacent to the point of measurement and eliminates the necessity of a long water column, which is present in standard tensiometers.

The pressure transducers are connected to Campbell Scientific Inc. dataloggers (i.e., Models 510X, 10X, 23X, or CR23) or a Tumut Gadara datalogger. This system collects continuous water-potential measurements at each instrumented depth. Data are collected at least every four hours, and dataloggers are generally downloaded on a monthly basis. Pressure transducers are calibrated before installation, field checked periodically, recalibrated after field placement (if measurements were questionable), and replaced as needed. Measurements are corrected for the pressure of a 12-cm hanging water column located above the pressure transducer. Readings are recorded in pressure units of centimeters of water relative to atmospheric pressure. The bottom sealing technique and sensor electronics are the same in all of the pressure transducers, while several different tubing and venting configurations have been used to improve the ease of handling, installation, and maintenance. Sensors for the advanced tensiometers measure over the range of plus or minus 800 cm water pressure; therefore, they can be used to measure in both the unsaturated tensiometric range or measure the depth of standing water should perched water conditions be observed.

In FY 2004, new wells were constructed and instrumented at RWMC with an array of vadose zone monitoring instruments. Advanced tensiometers were installed in Wells 1898, 1935, 1936, 2004, 2005, and 2006 (Oberhansley 2004, Oberhansley and Hubbell 2004, ICP 2004). Wells 1935 and 1936 were completed with tensiometers and lysimeters to observe water movement from the spreading areas (see Figure 3-5), to quantify the moisture status, and to allow sampling at these sites. Wells 2004, 2005, and 2006 were drilled to monitor and evaluate moisture movement through the vadose zone and to provide organic vapor data for the southeast corner of the SDA. Well 2004 had multiple tensiometers placed in the sedimentary interbeds to calculate hydraulic gradients for transport calculations. Table 3-2 lists and provides information on the advanced tensiometers installed in the deep vadose zone at RWMC.

Deep and shallow-perched water wells are monitored for the presence and depth of standing water. Locations and information for the deep wells and shallow surficial sediment access tubes are shown in Figure 3-5 and Table 3-2, respectively.

The shallow moisture-monitoring surficial sediment access tubes were installed between pits and trenches and in areas of interest from several projects that date from the 1960s to the mid-1990s. These tubes were designed to allow access for neutron moisture monitoring through the walls of the tubing. The tubing inner diameter is 3.8 or 5.1 cm (1.5 or 2.0 in.) (Schedule 40 steel). The tubes have a cap on top and are open on the bottom to the underlying geologic media (i.e., basalt or sediment) to allow water to enter the base. The tubes were installed by boring a small diameter hole through the surficial sediment to the basalt and sediment contact and then placing the tubing into the borehole and filling any annular space with native sieved sediment. In the mid-1990s, granular bentonite, mixed with an organic dye, was placed around the annular space to prevent and detect surface water from moving along the annular space on the exterior of the tubing (Bishop 1994).

Deeper perched water wells were drilled for various projects, and when perched water was suspected, the wells were completed at that point to allow water-level measurement in the perching layer. Manual water-level measurements were initially obtained from these sites and from data reported by Hubbell (1993 and 1995) and McElroy (1996). Perched water in the neutron access tubes is typically detected only in the spring time and is associated with snowmelt and runoff in the disposal area and, periodically, in response to large precipitation events. Deep perched water has been present for extended periods in some wells, while other wells have only detected standing water periodically.

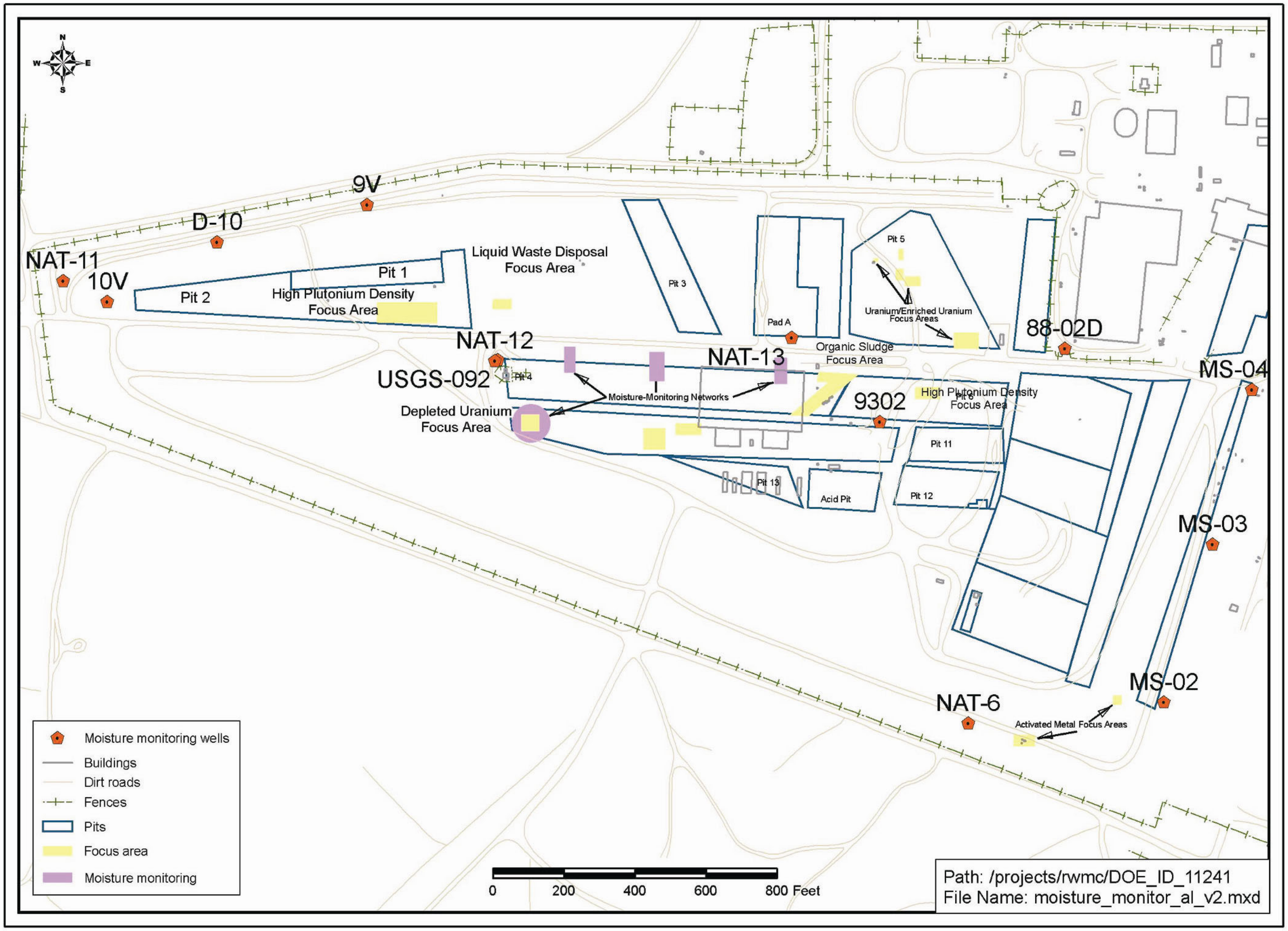


Figure 3-5. Map of the Subsurface Disposal Area showing locations of monitoring wells and focus areas.

Table 3-2. Well names, instrument depths below land surface, lithology adjacent to each instrument, and water-potential trends based on February 16, 2003, and February 16, 2004, measurements.

Well	Tensiometer/ Instrument Depth[a] (ft bls)	Lithology at Instrument Depth[b]	Water Potential (cm water) 2/16/2003	Water Potential (cm water) 2/16/2004
I-1S	103	B-C sedimentary interbed	-29	-29
I-1D	227	C-D sedimentary interbed	-372	-389
I-2S	94	Unknown, no recovery and no gamma log	-106	-95
I-2D	176	Basalt, massive	-78	-80
I-2D	223	C-D sedimentary interbed	-250	-242
I-3S	93	B-C sedimentary interbed	-66	-75
I-3D	229	C-D sedimentary interbed	-218	-215
I-4S	97	Basalt/B-C sedimentary interbed, near contact	-95	-95
I-4D	227	C-D sedimentary interbed	-220	-233
I-5S	100	Basalt/B-C sedimentary interbed, near contact	-137	-103
O-1	97	B-C sedimentary interbed, no recovery	-151	-152
O-2	107	Basalt/B-C sedimentary interbed, near contact	-131	-129
O-3	88	Basalt	-258	-235
O-3	221	Basalt/C-D sedimentary interbed	-98	-109
O-4	110	B-C sedimentary interbed	-208	-250
O-4	226	C-D sedimentary interbed	-302	-297
O-5	105	Basalt/B-C sedimentary interbed[c]	-142	-150
O-7	121	B-C sedimentary interbed, no recovery	-190[d]	-189
O-7	241	Basalt, rubbly	-27[d]	-27
76-5	22	Sediment-filled fractures	-289	-368
76-5	31	A-B sedimentary interbed[e]	-266	-291
76-5	38	Rubble zone	-172	-200
76-5	57	Horizontal fracture with sediment	-64	-77
76-5	80	Sediment-filled fractures	-101	-110
76-5	97	Moist basalt	-69	-83
76-5	103	B-C sedimentary interbed	-158	-156
77-2	33	A-B sedimentary interbed,[e] reddish-baked silt	-284	-308
77-2	56	Basalt	-131	-140
77-2	90	Basalt	-80	-80
78-1	35	Fractured basalt, with sediment infilling	-372	-393

Table 3-2. (continued).

Well	Tensiometer/ Instrument Depth[a] (ft bls)	Lithology at Instrument Depth[b]	Water Potential (cm water)	
			2/16/2003	2/16/2004
1935	41	A-B sedimentary interbed, silty clayey sand, slightly moist (interbed at 38 to 44 ft)	NA	NA
1935	98	B basalt fractured, slightly moist	NA	NA
1935	136	B basalt dense, dry	NA	NA
1935	20	C basalt fractured, slightly moist	NA	NA
1935	237	C-D interbed, silty clayey sand, slightly moist (interbed at 233 to 242 ft)	NA	NA
1935	250	D basalt, slightly moist	NA	NA
1935	281	D or E basalt, moist-slightly moist	NA	NA
1935	320.8	D or E basalt, fractured	NA	NA
1935	336.5	D or E basalt, fractured, moist-slightly moist	NA	NA
1935	356	D or E basalt, fractured, moist-slightly moist	NA	NA
1935	385	D or E basalt, slight moist	NA	NA
1936	32	A-B interbed, silty clayey sand, slightly moist	NA	NA
1936	104	B-C interbed, silty clayey sand, slightly moist, (interbed at 100 to 104 ft)	NA	NA
1936	115	B-C interbed, silts and sand with pebbles, slightly moist (interbed at 105 to 117 ft)	NA	NA
1936	145	C basalt, fractured and slightly moist	NA	NA
1936	184	Silty clayey sand, slightly moist (interbed at 184 to 185 ft)	NA	NA
1936	211	C basalt, slightly vesicular, dry	NA	NA
1936	235	C-D interbed, silty clayey sand, slightly moist (interbed at 231 to 235 ft)	NA	NA
1936	272	D basalt, vesicular, dry	NA	NA
1936	304	D or E basalt, vesicular fractured, slightly moist	NA	NA
1936	344	D or E basalt, fractured, dry	NA	NA
1936	373	D or E basalt, fractured, slightly moist	NA	NA
2004	16.5	Surficial sediments, silty clayey sand	NA	NA
2004	102	B-C interbed silty sand top	NA	NA
2004	106	B-C interbed, silty sand	NA	NA
2004	242	C-D interbed, silty sand, slightly moist	NA	NA
2004	249	C-D interbed, silty sand, slightly moist	NA	NA

Table 3-2. (continued).

Well	Tensiometer/ Instrument Depth[a] (ft bls)	Lithology at Instrument Depth[b]	Water Potential (cm water) 2/16/2003	2/16/2004
2005	8.9	Surficial sediments, silty clayey sand, slightly moist; waste at 14 ft	NA	NA
2006	11	Surficial sediments, silty clayey sand, slightly moist; basalt at 13 ft	NA	NA
2006	107	B-C interbed, silty sand; slightly moist	NA	NA
2006	237	C-D interbed, silty sand (interbed at 236 to 246 ft); slightly moist	NA	NA
1898	226	C-D interbed	NA	NA
9V	88[f]	Perched water well, above B-C interbed		
10V	97.5[f]	Perched water well, above B-C interbed		
D10	205.5[f]	Perched water well, above C-D interbed		
USGS 92	213.5	Perched water well, above C-D interbed		
8802	221.1	Perched water well, above C-D interbed		
9302	233 [f]	Perched water well, above C-D interbed		
MS-02	<20	Neutron access tube, surficial sediment-basalt contact		
MS-03	<20	Neutron access tube, surficial sediment-basalt contact		
MS-04	10	Neutron access tube, surficial sediment-basalt contact		
NAT-6	12.8	Neutron access tube, surficial sediment-basalt contact		
NAT-11	13.1	Neutron access tube, surficial sediment-basalt contact		
NAT-12	19.9	Neutron access tube, surficial sediment-basalt contact		
NAT-13	16.2	Neutron access tube, surficial sediment-basalt contact		

a. Tensiometers at Wells O1-229, O2-241, O8-229, O6-227 (may be in bentonite), and 78-1 (84 ft) (not operational) are excluded from this listing.

b. Basalt comprises about 90% of the stratigraphy between land surface and the underlying Snake River Plain Aquifer. The upper 230 ft of the subsurface is composed of three primary basalt flow groups called the A, B, and C basalts (i.e., USGS = U.S. Geological Survey nomenclature).

c. Discrepancy between geologist log and gamma log for Well O-5. Used natural gamma log placement of interbed at 106 ft bls.

d. Measurements from February 20, 2003, at 4:00 p.m. because no data exist for February 16, 2003.

e. Sedimentary interbed, not continuous, located approximately 26 ft bls.

f. Below measuring point.

NA = not available

In the mid-1990s, pressure sensors (with dataloggers) were placed at the base of the tubing in both the shallow and deep perched water monitoring sites to allow unattended water-level measurement over months and years. This practice was discontinued in the late 1990s. In spring 2003, dataloggers and pressure sensors[d] were placed in these deep perched water wells and neutron access tubes to obtain

d. Instruments are from Electronic Engineering Innovations, Las Cruces, New Mexico.

continuous water-level measurements. The pressures are measured, relative to atmospheric pressure, to detect the presence of water and to record the pressure exerted by the water depth. Water levels are measured on an hourly basis, and dataloggers are downloaded monthly.

3.2 Soil-moisture, Resistivity, and Temperature and Direct-push Type B Tensiometer Sensors

The SMR and DPT instruments are located in focus areas that were established to investigate specific waste types (Meyers et al. 2005). Focus areas are shown in Figure 3-6. Detailed location maps within focus areas are presented in the *Final Report for the Waste Area Group 7 Probing Project* (Meyers et al. 2005). The installation objective for both the SMRs and the DPTs was to instrument the waste zones, targeting the top of the waste, the waste, and where underburden and waste are in contact, or immediately above the underlying basalt, as conditions allowed. In most instances, the DPTs were paired with SMRs. The SMRs were typically installed with three instruments on a string, so that each sensor was directly below the one above it. The DPTs are independent installations and were typically installed in proximity at different depths, again targeting the top of the waste, the waste, and the soil beneath the waste. Several of the moisture-monitoring sites are not located within waste, but are located at similar depths as those instruments in waste. Data generated by these instruments were collected on dataloggers, typically taking measurements at two-hour intervals.

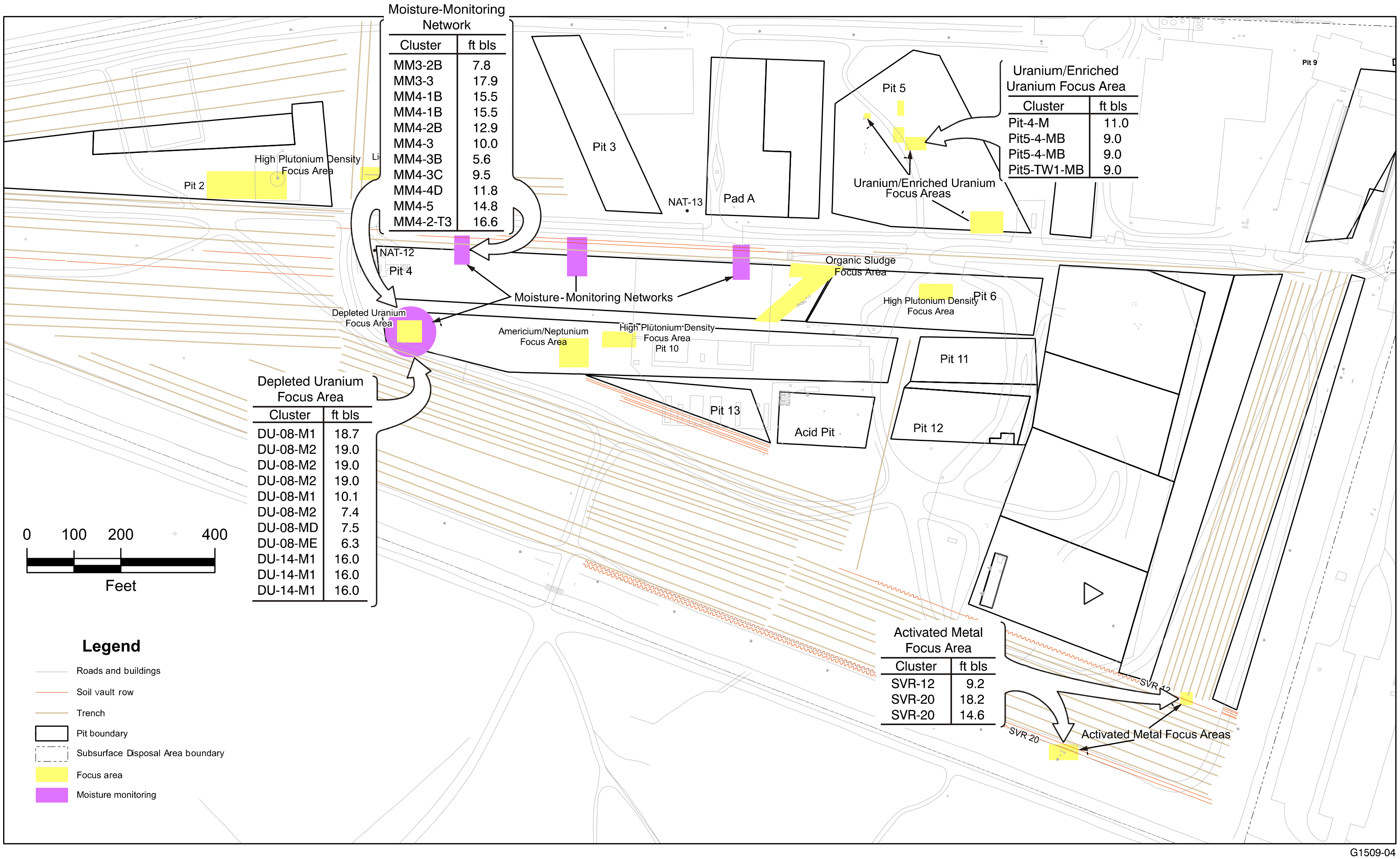
The tensiometers are periodically serviced by adding water to the water chamber. This produces a characteristic response where the pressure decreases and then levels off as indicated in Figure 3-7. The instrument was serviced on June 24 and then the pressure decreased until it reached pressure equilibration on July 6, 2004. The data following that date is the water potential of the sediment and the oscillations in the data are from changes in barometric pressure.

3.2.1 Soil-moisture, Resistivity, and Temperature Sensors

The SMR sensors provide temporal soil-moisture, resistivity, and temperature data. The SMR sensors (see Figure 3-3) are manufactured by Applied Research Associates and consist of a body made of 4340 carbon steel that has been heat treated. A series of electrode rings, made of Type 304 stainless steel and located near the lower end of the instrument, is used to take the measurements.

The SMR sensors installed at RWMC were specially adapted and strengthened to withstand installation in waste. Special precautions were devised that rendered the sensors slightly different from the standard, off-the-shelf item. These changes (e.g., addition of potting material inside the sensor to stabilize the electronics) resulted in sensitivity to temperature. Where available, an equation was applied to the data to remove temperature impacts (see Appendix D for temperature corrections).

Ninety-five SMR sensors in 51 instruments were pushed into the soil and waste at RWMC. Seventy-three percent of the network of 95 sensors is providing usable data. Twenty-six of the 95 sensors have been abandoned because of location or malfunction. Table 3-3 provides identification and depth information for the working SMRs installed in the SDA.



Moisture-Monitoring Network

Cluster	ft bls
MM3-2B	7.8
MM3-3	17.9
MM4-1B	15.5
MM4-1B	15.5
MM4-2B	12.9
MM4-3	10.0
MM4-3B	5.6
MM4-3C	9.5
MM4-4D	11.8
MM4-5	14.8
MM4-2-T3	16.6

Uranium/Enriched Uranium Focus Area

Cluster	ft bls
Pit-4-M	11.0
Pit5-4-MB	9.0
Pit5-4-MB	9.0
Pit5-TW1-MB	9.0

Depleted Uranium Focus Area

Cluster	ft bls
DU-08-M1	18.7
DU-08-M2	19.0
DU-08-M2	19.0
DU-08-M2	19.0
DU-08-M1	10.1
DU-08-M2	7.4
DU-08-MD	7.5
DU-08-ME	6.3
DU-14-M1	16.0
DU-14-M1	16.0
DU-14-M1	16.0

Activated Metal Focus Area

Cluster	ft bls
SVR-12	9.2
SVR-20	18.2
SVR-20	14.6

Figure 3-6. Map of the Subsurface Disposal Area showing focus areas in yellow where the shallow vadose zone instrumentation is installed.

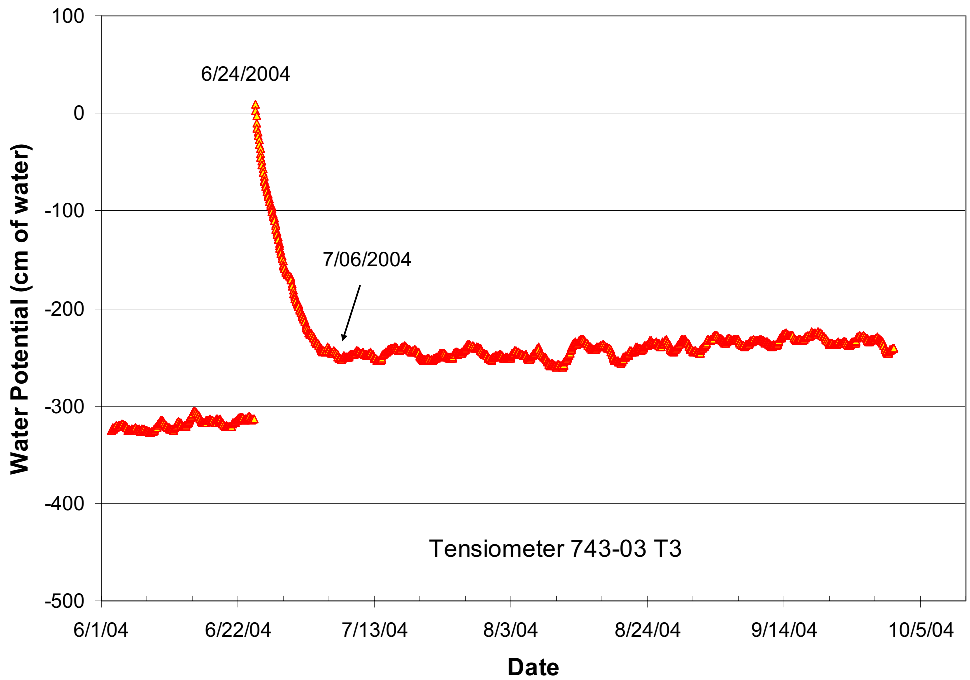


Figure 3-7. Illustration showing data from a direct-push Type B tensiometer sensor. Trend shows sensor coming to equilibrium after being serviced in June 2004.

Table 3-3. List of functioning soil-moisture, resistivity, and temperature sensor instrumentation in the Subsurface Disposal Area focus areas.

Integrated Probing Project Focus Area	Probe Name	Installation Date	Sensor Identification Number	Sensor Depth from Surface (ft)
Americium/neptunium	741-08-M1	07/09/01	266	19.86
Americium/neptunium	741-08-M1	07/09/01	267	4.14
Americium/neptunium	741-08-M1	07/09/01	268	11.50
Organic sludge	743-03-M1 [a]	04/24/01	235	3.36
Organic sludge	743-03-M1 [a]	04/24/01	237	19.09
Organic sludge	743-03-M2	11/25/03	2A6	18.54
Organic sludge	743-03-M2	11/25/03	2A8	12.46
Organic sludge	743-08-M1 [a]	04/30/01	247	6.60
Organic sludge	743-08-M1 [a]	04/30/01	250	13.90
Organic sludge	743-08-M1 [a]	04/30/01	251	22.28
Organic sludge	743-18-M1 [a]	04/30/01	217	6.47
Organic sludge	743-18-M2 [a]	11/26/03	2B0(210) [b]	8.16
Organic sludge	743-18-M3 [a]	12/02/03	2A9	19.16

Table 3-3. (continued).

Integrated Probing Project Focus Area	Probe Name	Installation Date	Sensor Identification Number	Sensor Depth from Surface (ft)
Depleted uranium	DU-08-M1	07/10/01	269	11.50
Depleted uranium	DU-08-M2	11/24/03	298	12.08
Depleted uranium	DU-08-M2	11/24/03	299	6
Depleted uranium	DU-08-M2	11/24/03	2A0(100) [b]	18.6
Depleted uranium	DU-10-M1	07/11/01	264	9.25
Depleted uranium	DU-10-M2	07/11/01	271	6.64
Depleted uranium	DU-10-M3	07/11/01	263	3.97
Depleted uranium	DU-10-MD	08/20/01	277	6.72
Depleted uranium	DU-10-ME	11/20/03	296	5.5
Depleted uranium	DU-14-M1	07/16/01	276	15.20
Depleted uranium	DU-14-M1	07/16/01	278	9.83
Depleted uranium	DU-14-M1	07/16/01	280	4.47
Depleted uranium	DU-14-M2	11/20/03	297	12
Liquid waste disposal	HAL2-M1	08/11/04	2A5	20.4
Liquid waste disposal	HAL2-M2	08/11/04	2A7	20.8
Moisture monitoring	MM2-1	03/28/01	231	16.00
Moisture monitoring	MM2-1B	04/18/01	241	12.51
Moisture monitoring	MM2-2	03/28/01	224	10.78
Moisture monitoring	MM2-2B	04/18/01	222	9.14
Moisture monitoring	MM2-3	03/28/01	215	3.05
Moisture monitoring	MM2-3B	04/23/01	246	1.67
Moisture monitoring	MM3-1	03/22/01	242	9.69
Moisture monitoring	MM3-1B	05/14/01	253	7.62
Moisture monitoring	MM3-1C	05/14/01	245	4.47
Moisture monitoring	MM3-2	03/26/01	210	8.53
Moisture monitoring	MM3-2B	05/14/01	252	6.96
Moisture monitoring	MM3-2C	05/14/01	216	3.97
Moisture monitoring	MM3-3	03/26/01	225	17.00
Moisture monitoring	MM3-3B	05/14/01	244	13.82
Moisture monitoring	MM3-3B	05/14/01	254	7.46
Moisture monitoring	MM4-1B	07/16/01	286	14.67
Moisture monitoring	MM4-1B	07/16/01	287	6.30
Moisture monitoring	MM4-1D	08/21/01	272	16.72
Moisture monitoring	MM4-2B	07/10/01	273	12.08

Table 3-3. (continued).

Integrated Probing Project Focus Area	Probe Name	Installation Date	Sensor Identification Number	Sensor Depth from Surface (ft)
Moisture monitoring	MM4-2B	07/10/01	275	4.72
Moisture monitoring	MM4-3	03/01/01	218	9.11
Moisture monitoring	MM4-3B	05/21/01	243	6.18
Moisture monitoring	MM4-3C	06/12/01	255	4.80
Moisture monitoring	MM4-4B	06/12/01	256	8.72
Moisture monitoring	MM4-4B	06/12/01	257	4.17
Moisture monitoring	MM4-5	03/08/01	234	13.88
Moisture monitoring	MM4-5B	07/16/01	239	9.75
Pit 2 high-plutonium density	P2-PU-M1	08/16/04	262	19.0
Pit 2 high-plutonium density	P2-PU-M2	08/18/04	249	19.0
Pit 6 high-plutonium density	P6-PU-M	08/05/04	2A3	3.9
Pit 6 high-plutonium density	P6-PU-M	08/05/04	2A4	14.5
Uranium/enriched uranium	P5-UEU-M	08/04/04	2A2	3.0
Uranium/enriched uranium	P5-UEU-M	08/04/04	2B1	4.3
Uranium/enriched uranium	Pit5-4-M	08/14/01	285	10.16
Uranium/enriched uranium	Pit5-4-MB	08/14/01	279	8.18
Uranium/enriched uranium	Pit5-4-MB	08/14/01	289	2.81
Uranium/enriched uranium	Pit5-TW1-M	08/14/01	282	10.24
Uranium/enriched uranium	Pit5-TW1-MB	08/15/01	290	2.85
Activated metal stainless steel	SVR-12-MB	07/25/01	281	4.30
Activated metal stainless steel	SVR-12-MB	07/25/01	283	8.39
Activated metal stainless steel	SVR-12-M [a]	07/25/01	284	11.45
Activated metal beryllium	SVR-20-M [a]	09/06/01	260	4.43
Activated metal beryllium	SVR-20-M [a]	09/06/01	259	13.79
Activated metal beryllium	SVR-20-M [a]	09/06/01	258	17.44

a. Probes discontinued.

b. ( ) alias name of sensor.

3.2.2 Direct-push Type B Tensiometers

Direct-push Type B tensiometers (see Figure 3-4) measure the water potential of soil water in the surficial sediments in the SDA. Tensiometers were placed in locations to provide data on the moisture conditions within the waste zones, to quantify the amount and timing of moisture infiltration, and to define the presence and extent of any saturated conditions (Salomon 2004). The DPT functions in a manner similar to the advanced tensiometer, which is described in greater detail in Section 3.1.

Sixty-six DPTs were installed in the SDA in nested groups of three. Thirty-four of the DPTs (or 52%) provided data (water potential or trend data) during portions of FY 2004. Table 3-4 lists DPT identification information and installation depths. The upper group (T1) was placed near the contact between the overburden and upper waste zone; the middle group (T2) was placed in the upper third of the waste zone; and the lower group (T3) was placed at the underburden and waste contact, or immediately above the underlying basalt, as conditions allowed. In most instances, the tensiometers were paired with SMRs. Data generated by these instruments were collected on dataloggers, typically taking measurements at two-hour intervals.

The inner workings of the DPT include permanent valves, tubing, and sensors, producing a single-purpose, dedicated instrument exclusively for measuring water potential. Some of the DPTs appear to have been adversely affected by the installation technique, damaging the sensors or affecting the calibration. It also appears some sensors have had electronic malfunctions, including poor electrical connections and/or datalogger problems. In addition to installation damage, the DPT data are further impacted by the servicing schedule. Following servicing, the DPTs may take weeks to several months to come back into soil-water potential equilibrium with the soil.

Table 3-4. List of direct-push Type B tensiometers installed in the Subsurface Disposal Area focus areas.

Integrated Probing Project Focus Area	Probe Name	Sensor Depth from Surface (ft)
Americium/neptunium	741-08-T3	19.9
Organic sludge	743-03-T1	5.3
Organic sludge	743-03-T3	18.5
Organic sludge	743-18-T1	5.5
Depleted uranium	DU-08-T3	16.4
Depleted uranium	DU-10-T2	6.7
Depleted uranium	DU-10-T3	9.1
Moisture monitoring	MM1-1-T2	10.5
Moisture monitoring	MM1-1-T3	17.7
Moisture monitoring	MM1-2-T2	9.3
Moisture monitoring	MM2-1-T2	11.9
Moisture monitoring	MM2-1-T3	16.0
Moisture monitoring	MM2-2-T2	8.6
Moisture monitoring	MM2-2-T3	5.1
Moisture monitoring	MM2-3-T2	5.1
Moisture monitoring	MM3-1-T3	9.7
Moisture monitoring	MM3-2-T1	5.0
Moisture monitoring	MM3-2-T2	6.6
Moisture monitoring	MM3-2-T3	8.4

Table 3-4. (continued).

Integrated Probing Project Focus Area	Probe Name	Sensor Depth from Surface (ft)
Moisture monitoring	MM3-3-T2	4.6
Moisture monitoring	MM4-1-T1	5.7
Moisture monitoring	MM4-1-T2	14.9
Moisture monitoring	MM4-1-T3	18.5
Moisture monitoring	MM4-2-T1	4.9
Moisture monitoring	MM4-2-T2	11.4
Moisture monitoring	MM4-2-T3	15.8
Moisture monitoring	MM4-4-T2	8.2
Moisture monitoring	MM4-4-T3	9.5
Moisture monitoring	MM4-5-T2	9.7
Moisture monitoring	MM4-5-T3	13.5
Activated metal	SVR12-1-T1	3.6
Activated metal	SVR12-1-T2	8.4
Activated metal	SVR20-1-T2	12.7
Activated metal	SVR20-1-T3	16.4

4. DATA AND ANALYSIS OF ADVANCED TENSIOMETER MONITORING IN THE DEEP VADOSE ZONE

Well-completion information (Dooley and Higgs 2003) and data from the existing advanced tensiometer network wells have been described by McElroy and Hubbell (2003, 2004a, and 2004b). Well completions and previous data from the perched water wells were documented by Hubbell (1990, 1992, 1993, and 1995). Drilling, geology, and well completion information from the five new wells are presented by Oberhansley (2004) and Oberhansley and Hubbell (2004).

Six new wells were instrumented with multiple tensiometers from April to June 2004. Two wells (1935 and 1936), located west and southwest of the SDA, were placed to detect the presence of perched water lateral flow between the SDA and the spreading areas to the west and south of the SDA (Figure 2-4). These sites also expand the tensiometer-monitoring network and provide data for about a 122-m (400-ft) depth. Two wells (2004 and 2006) were drilled in the eastern and southeastern portion of the SDA and provide data on stratigraphy and interbed thickness to below the C-D interbed. Tensiometers were placed at the contact between surficial sediment and basalt and within the B-C and C-D interbeds to evaluate the hydraulic gradients. Well 2005, located south of 2004, encountered waste materials at 4.3 m (14 ft) below land surface (bls) while the surficial sediment was being drilled; therefore, the well was completed with a tensiometer to about 2.4 m (8 ft) deep. Well 1898 was drilled from September to October 2003 and instrumented with one tensiometer at a depth of 69 m (226 ft).

4.1 Advanced Tensiometers Network

In FY 2004, the deep vadose zone monitoring network included 67 advanced tensiometers in 26 wells; however, several tensiometers are not operational and are not included in Table 3-2. Instrument locations are shown in Figure 4-1 with details of the individual tensiometers and perched water monitoring locations listed in Table 3-2. These instruments range in depth from about 3 to 117 m (8 to 385 ft) bls.

4.2 Data and Methodology

Data from the advanced tensiometers show one of three trends: decreasing, increasing, or steady water potentials. When analyzing the temporal response of a single tensiometer, the lower (more negative) the water-potential measurement, the dryer the material. Therefore, decreasing water potentials indicate drying of the medium, while increasing water potentials indicate wetting of the medium. A water potential of zero indicates the presence of the top of the water table, with positive water potentials indicating saturated conditions (depth of water above the transducer [cm]), and negative water potentials indicating unsaturated conditions.

Water potentials that do not change significantly over time suggest steady-state conditions, implying a constant water flux in a downward direction. All of these instruments have minor trends that are biased by the barometric effects, water-column changes over time, instrument drift, lysimeter-sampling influences, and water-potential changes. Steady state is relative to the monitored period; some long-term changes in water potentials may not be large enough to discern over the time period.

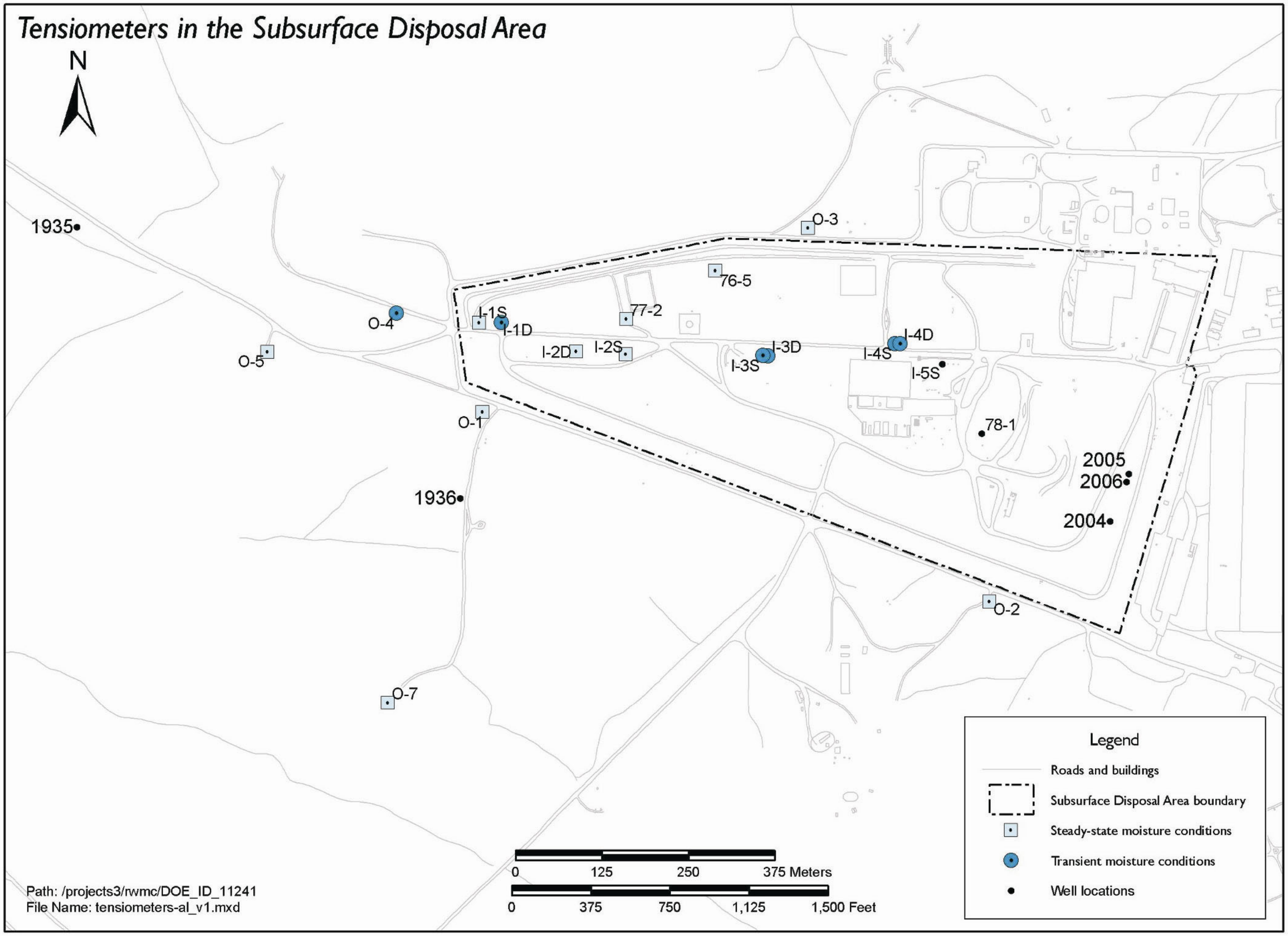


Figure 4-1. Instrument locations of individual tensiometers.

Transient conditions imply changes in moisture over time, presumably from changes in infiltration at the land surface. Specific recharge events over short time periods (e.g., from snowmelt and runoff) may be identified because of the large changes in water potentials. Small changes in water potentials over long time frames are more difficult to discern. Several instruments have had these long-term changes become more evident as the monitoring period is extended. These long-term trends are arbitrarily defined in this report by the presence of a long-term shift in water potentials of more than 15 cm of water (based on the maximum column of water contained within the lower water reservoir of the tensiometers). Short-term data trends can be influenced by changes in barometric pressure because the pressure sensor is referenced to barometric pressure.

Water-potential data for boreholes installed before spring 2004 are shown in Figures 4-2 through 4-8 for spring 2000 through September 2004. Additionally, water-potential values at each location for February 16, 2003, and February 16, 2004, are listed in Table 3-2 to summarize the overall trend in the data over the past years. Data in Figures 4-2 through 4-8 are grouped by trending versus steady state water-potential data, along with location, depth, and lithology. Data from four multidepth nested wells drilled and completed in 2004 are presented by individual well in Figures 4-9 through 4-12.

Data from instruments in both basalt and sediments show drying trends in Figures 4-2 and 4-3. Locations showing steady water-potential trends are shown in Figure 4-4, 4-5, and 4-6. Two sites also indicate increasing water-potential trends outside the SDA in the B-C and C-D interbeds. Several of these sensors indicate both wetting and drying intervals, indicating they are sensitive to perturbations in seasonal infiltration events.

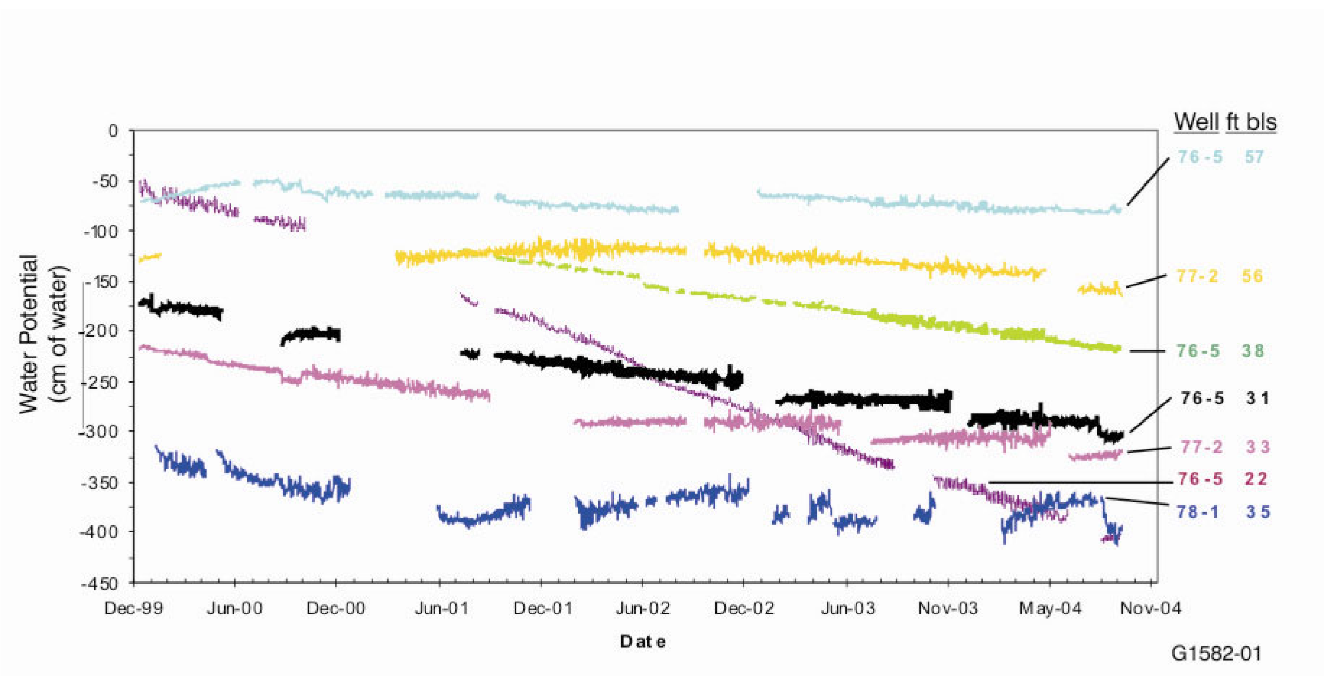


Figure 4-2. Advanced tensiometers showing long-term drying trends above the B-C interbeds.

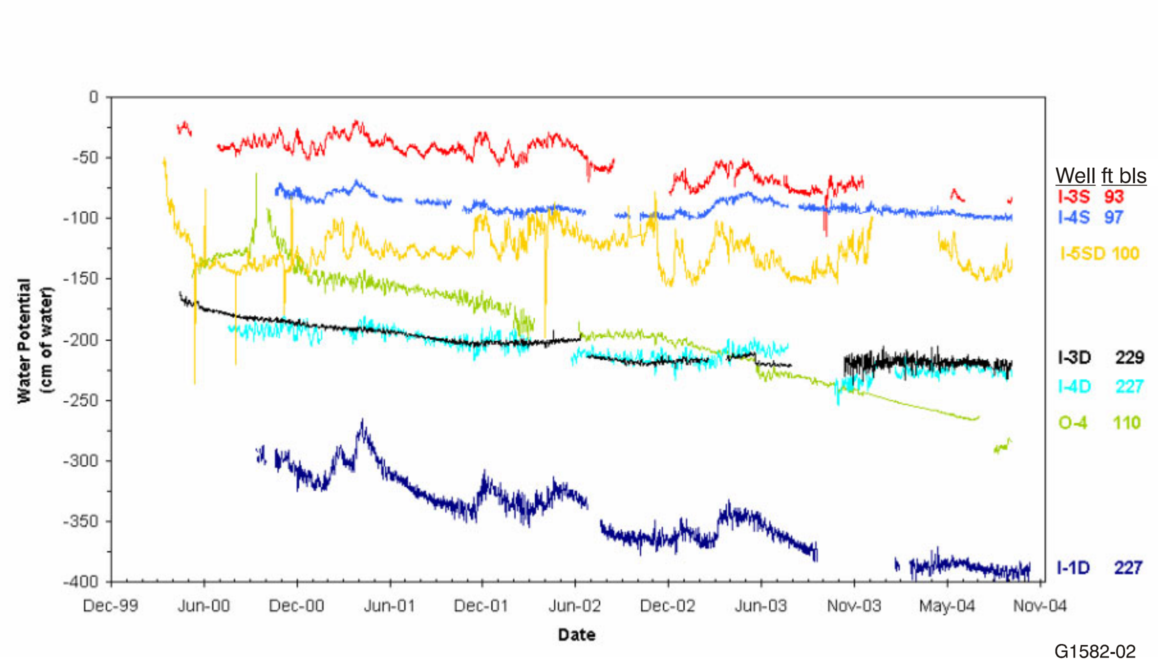


Figure 4-3. Advanced tensiometers showing long-term drying trends at or below the B-C interbed.

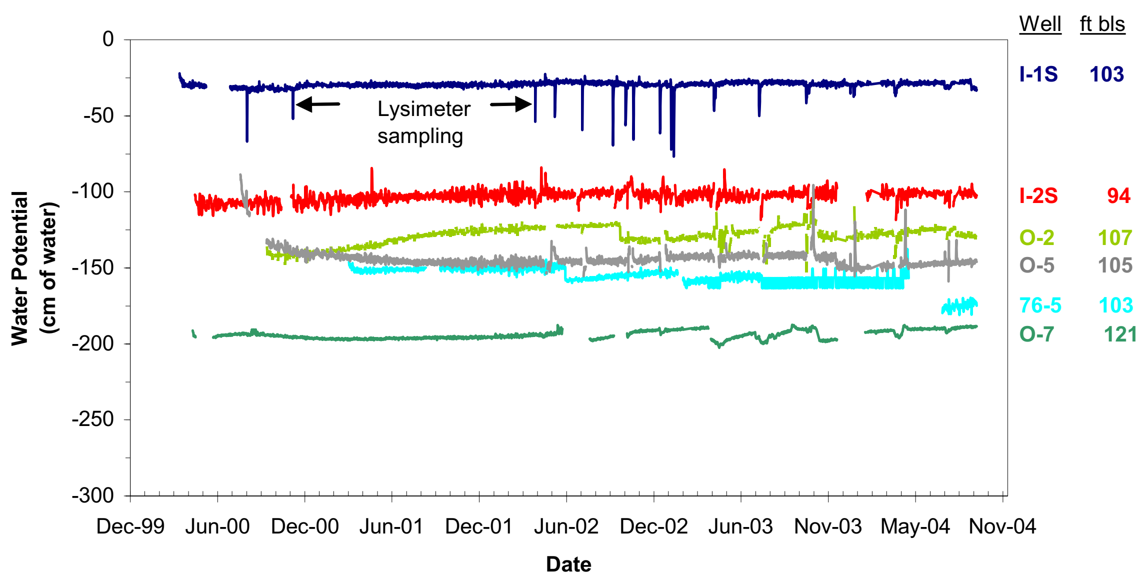


Figure 4-4. Advanced tensiometers showing stable water potentials in the B-C interbed.

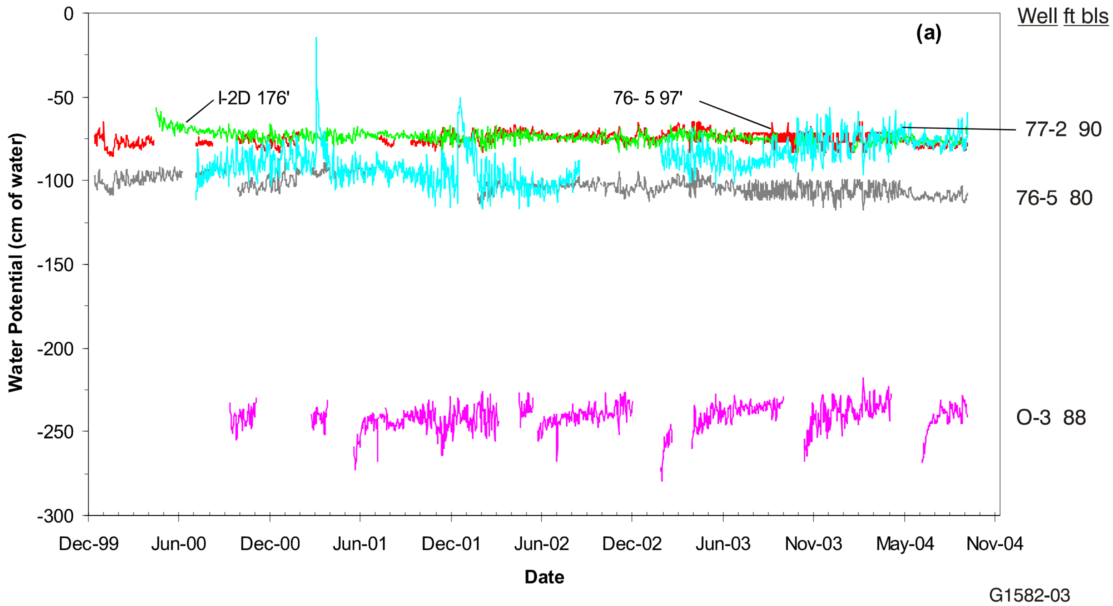


Figure 4-5. Advanced tensiometers showing stable water-potential measurements in the basalt.

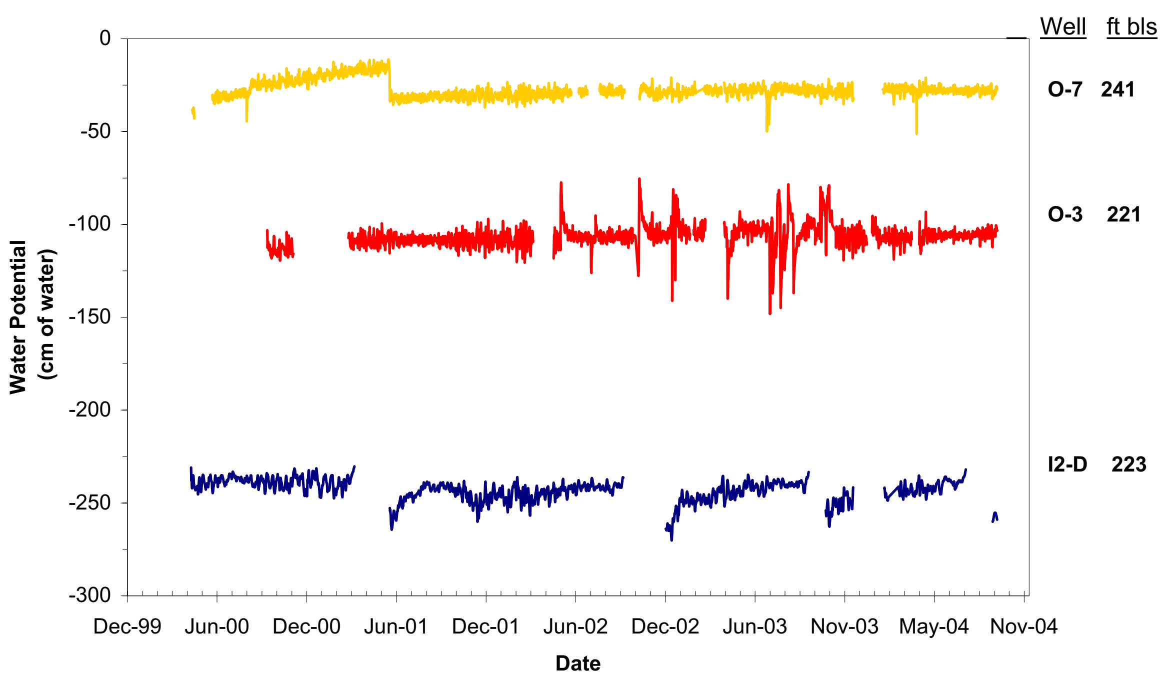


Figure 4-6. Stable water-potential measurements in the C-D interbed and the D basalt.

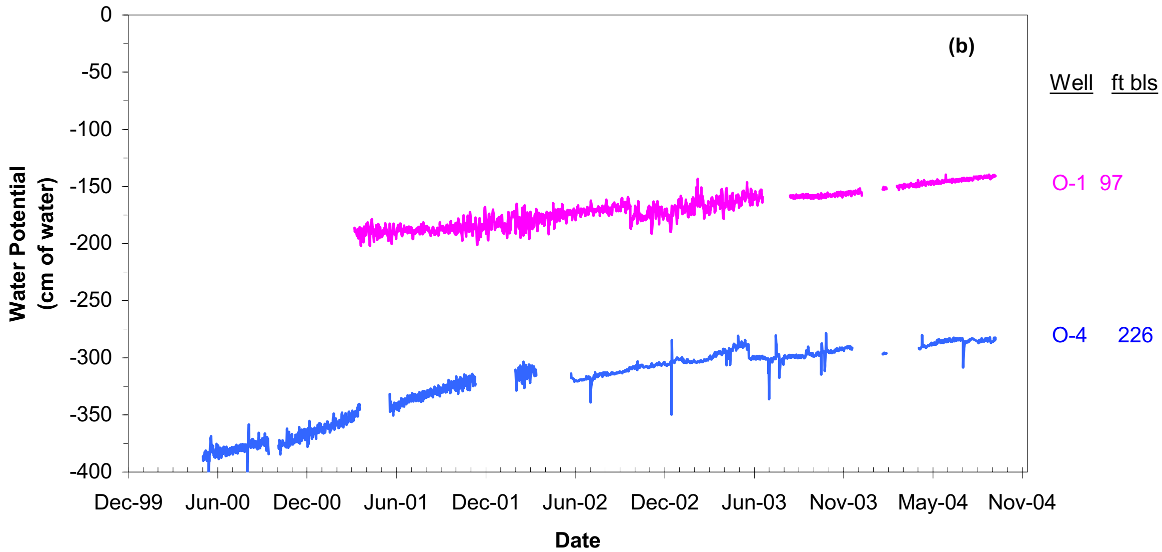


Figure 4-7. Wells with increasing water-potential data.

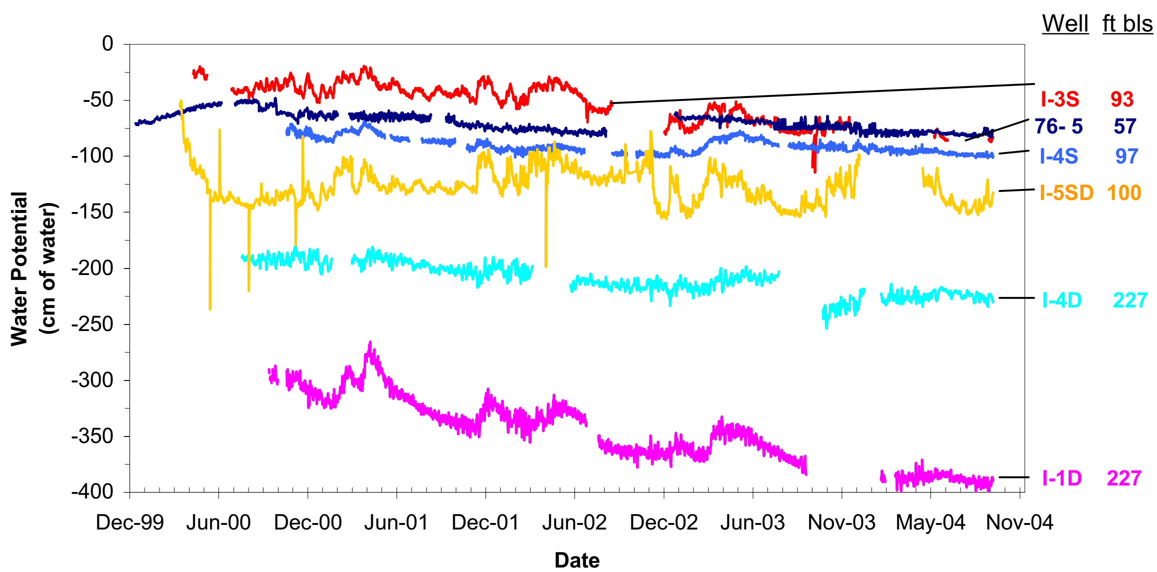


Figure 4-8. Advanced tensiometer data that appear to be sensitive to barometric pressure fluctuations.

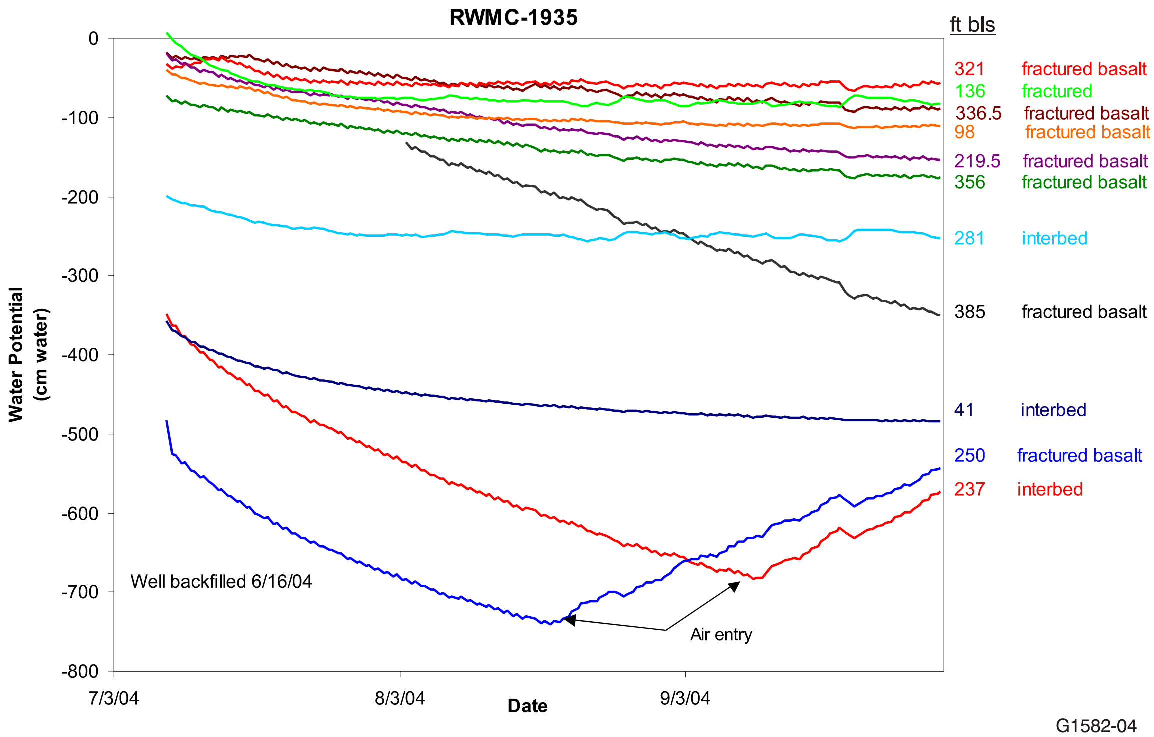


Figure 4-9. Water-potential data from Well 1935.

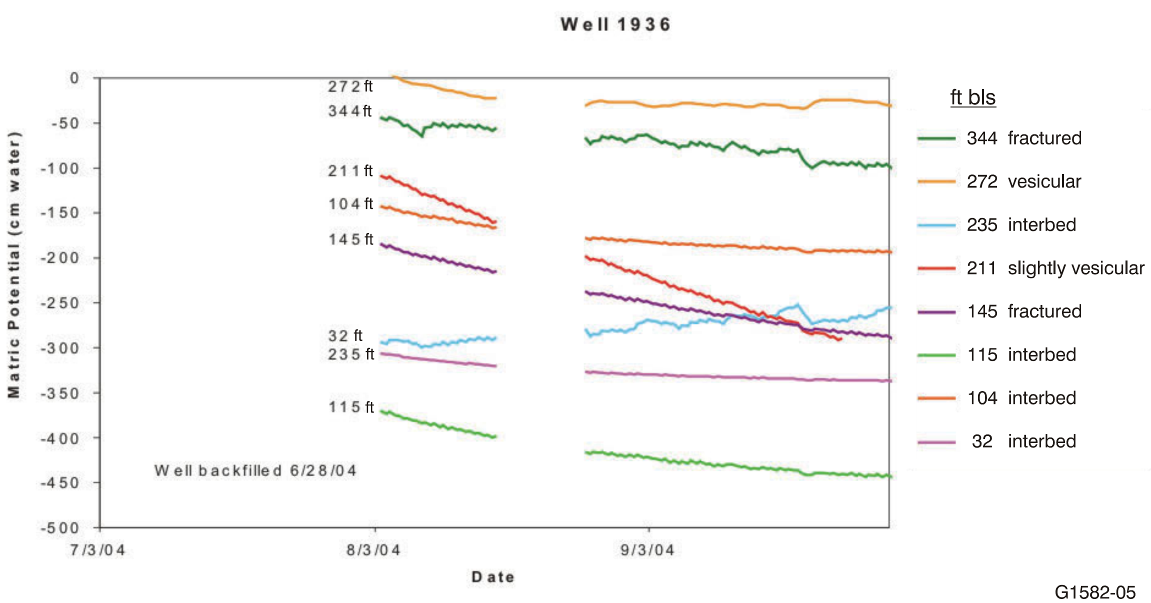


Figure 4-10. Water-potential data from Well 1936. The missing strip of data in the center of the figure shows where the datalogger malfunctioned.

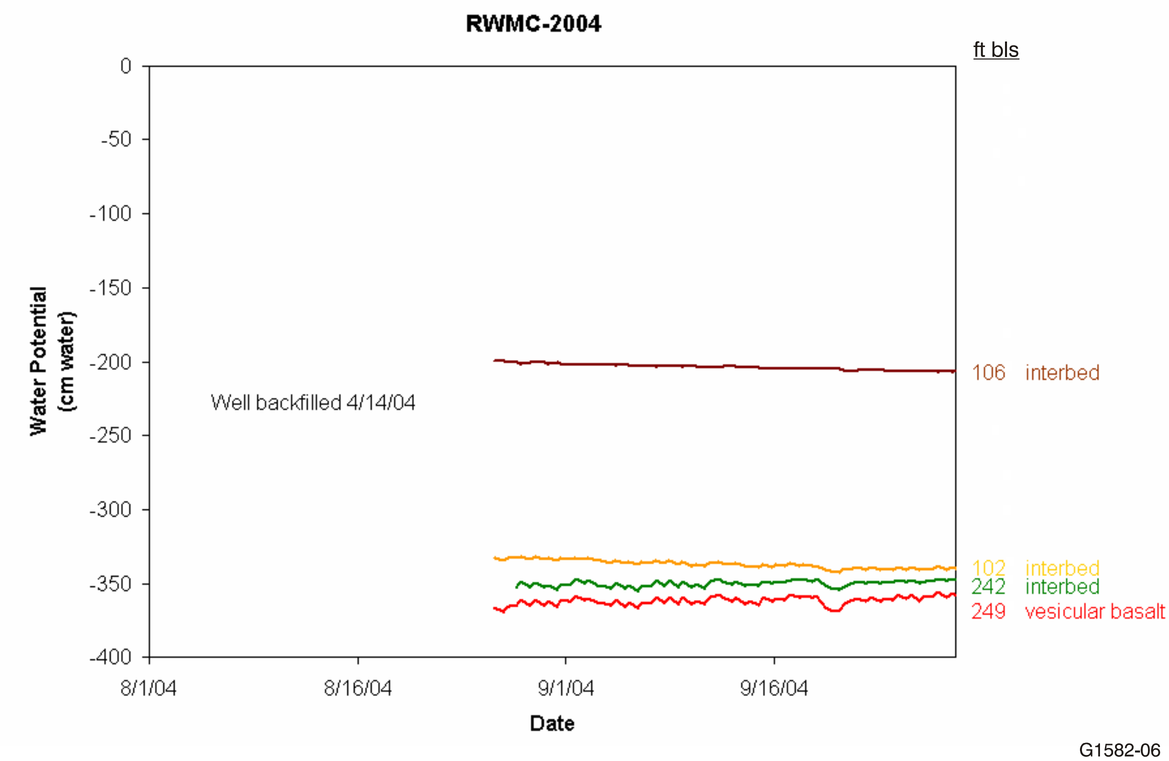


Figure 4-11. Water-potential data from Well 2004.

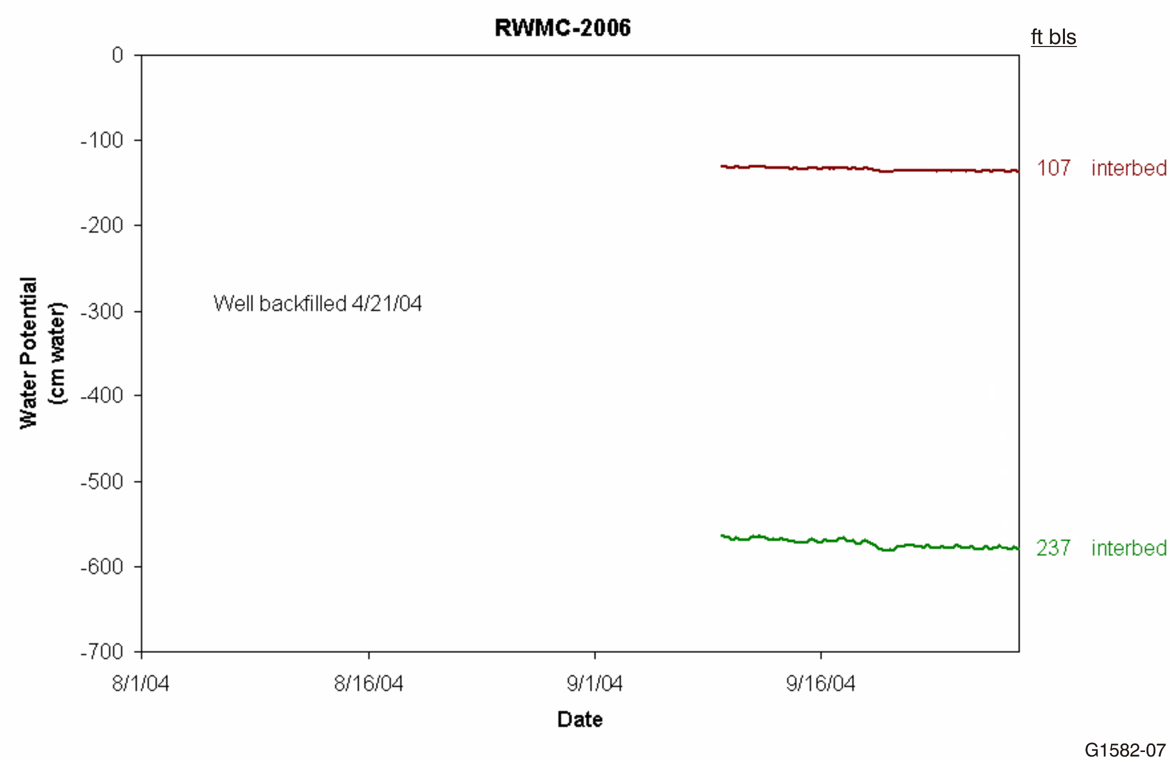


Figure 4-12. Water-potential data from Well 2006.

Water potentials ranged from a near-saturated -30 cm to approximately -400 cm of water. Those instruments that indicate water potentials above -450 cm are believed to be in contact with bentonite used to seal intervals of the wells and prevent preferential flow paths within the boreholes. These sensors are identified in Table 3-2, but graphs of their data are not included in this report. Data from the surficial sediment in the new wells are not included. There is a possibility that, with time, these sensors may equilibrate with the material surrounding the borehole, so the tensiometers are periodically filled with water and monitored to evaluate whether the sensors may produce representative data. To date, none of these sensors have provided data suggesting a water-potential equilibrium.

Data gaps in water-potential profiles were due to equipment malfunctions (e.g., battery, datalogger, or transducer failure) or loss of water from the tensiometer cup. Data spikes (toward lower water potentials and followed by an increase in water potential) are caused by the short-term influence of nearby suction-lysimeter sampling, as shown in Figures 4-4 and 4-6 for Wells I-1S and 0-3. These instruments show a pressure recovery from a few days, following a single vacuum application to about three weeks, when there were two vacuum applications (i.e., Well I-1S). The pressure response from suction-lysimeter sampling does not appear to influence the overall data or long-term trends in these instruments. The pressure response from suction-lysimeter sampling events was removed from most of the data in the figures to clarify the data presentation.

The advanced tensiometer data may be affected by equipment drift, barometric pressure fluctuations, and changes in the length of the hanging water column (less than 15 cm of water) from air entry into the water chamber. Long-term equipment drift is periodically checked when the sensor is pulled upward, so that the sensor is open to the atmospheric pressure to determine the “zero” relative pressure point (this is done when the lower water reservoir is filled with water). Barometric fluctuations have been left in the data to show the direct output from the sensors, but the fluctuations can be partially numerically removed by time-series averaging or deconvolution techniques. This response is due to differences between the sensors being referenced to atmospheric pressure, which differs from the gas pressure in the geologic media at the tensiometer porous cup. The hanging-water-column effect results from an accumulation of air in the lower water chamber over time. It is apparent in the graph for Well 02-107 (see Figure 4-4), where the data show a small increase in water potential over time, which is followed by a decrease following refilling the lower water reservoir.

The type of backfill used to complete the well may also influence data responsiveness and equilibration time following well installation. The backfill is chosen to provide a hydraulic connection to the monitored material while providing a consistent backfill media between sites. The fine-grained silica flour mixed with silica sand uses silica flour that is texturally similar to loam in the interbeds while the silica sand acts as a filler and facilitates filling voids and fractures. The several-meter-thick fine-grained backfill layers provide a composite measurement and may dampen infiltration and drainage. In fractured basalt, the fine-grained backfill dampens any response if there are pulses of moisture through the fractures; if there are no pulses of water, the backfill will come into equilibrium with the massive basalt rather than fast-flow paths.

Figures 4-9 to 4-12 (Wells 1935, 1936, 2004, and 2006) show data that may not be fully equilibrated with the surrounding materials. Of these, Well 1935 appears to be closest to equilibration in response to the high water-potential (wetter) material in the surrounding geologic media compared to the lower water-potential (dryer) material in the remaining wells. Two-month equilibration times were observed in well completions using dry backfill at Wells 76-5, 77-2, and 78-1 (Hubbell et al. 2002; McElroy and Hubbell 2003). Sisson, Schafer, and Hubbell (2000) found that wet backfill equilibrated much more rapidly (i.e., days) than dry backfill. Wet backfill was used in the construction of all of the wells noted above to reduce equilibration times; data collection did not begin for one to six months after the boreholes were backfilled.

4.3 Temporal Water-Potential Trends

Fiscal Year 2004 is the fifth year of drought with many tensiometers over the full range of depths responding with decreasing water potentials. Figure 4-2 presents data showing sites above the B-C interbed with decreasing water potentials while Figure 4-3 presents sites with decreasing water potentials to greater depths. Overall decreases (i.e., spring 2000 through September 2004) ranged from approximately 60 cm of water at Wells 781-35, 765-31, and 765-38 to approximately 400 cm of water at Well 765-22. Most of the tensiometers indicate a near linear drying trend while several suggest conditions may be approaching steady state.

Water-potential trends indicate that steady-state or drying conditions predominate in the deep vadose zone, with increasing water potentials being the exception. This trend extends to the C-D interbed (i.e., the maximum depth with a three- to four-year record). The new wells in the southeastern portion of the SDA (2004, 2005, and 2006) and outside of the SDA to the west and southwest (1935 and 1936) indicate water-potential equilibration with the surrounding media and are now starting to provide representative water-potential measurements at these depths and locations.

In FY 2004, long-term drying trends were observed at seven of the 25 deep locations. Decreases in water potential continued to be observed in the basalt at Well 765-57 (see Figure 4-2) and in B-C interbed sediments at Wells I3S-93 and I4S-97 until December 2002; and at Wells O4-110, I1D-227, I3D-229, and I4D-226 until March 2003. The decreasing water potentials at Wells 765-57 and O4-110 follow recharge events recorded in September and October 2000, respectively. At Well 765-57, the 7 cm offset (increase) in water potentials in late 2002 is the result of replacing the transducer, but the trend of decreasing water potentials continued. The cyclic rise and decline in water potentials (high frequency oscillations) that are most prominent in Wells I3S-93 and I1D-227, but also occur in Wells I4S-97 and I4D-226, appear to be related to barometric fluctuations. These fluctuations are possibly related to infiltration and drainage; however, no clear distinction can be drawn at this time. Water-potential decreases at these seven locations, from 2000 to September 2003, ranged from an overall decrease of approximately 16 cm at Well I4S-97, to a more substantial decrease of approximately -105 cm at Well O4-110.

Diminished precipitation and resultant infiltration over the last few years may have contributed to the decreased water potentials at the less than 17-m [56-ft]) depths (McElroy and Hubbell 2003). Annual precipitation has decreased to less than 14 cm for the past four years (2000 through 2003), which is less than the average annual precipitation of 22 cm/year (Clawson, Start, and Ricks 1989). Water potentials at each of the locations above 17 m (56 ft), with the exception of Well 765-38, have decreased to less than the steady-state values found before 1999 (McElroy and Hubbell 2003). The sediments and basalts above the B-C interbed (34 m [110 ft]) are likely to be responding to decreased surface infiltration.

The wells that reflect drying trends (except for Wells 765 and O4) are located along the main east-west drainage ditch that runs through the center of the SDA. The east–west ditches collect surface water from surrounding areas and focus runoff and infiltration along the road. Sedimentary interbeds and basalt beneath those areas of focused infiltration may be responding to decreased runoff from five years of less-than-average precipitation (2000 through 2004). Development of this hypothesis is limited by the lack of wells sited away from drainage ditches in the SDA and by the need for nested tensiometers near the ditches to track surface recharge. Wells I3S-93 and I3D-229 display nearly identical decreases in water potential over the monitoring period, suggestive of uniform moisture drainage of pore fluids over the monitored depths.

Another possible mechanism cited by McElroy and Hubbell (2003) for the observed drying trends is drainage following lateral underflow from the spreading areas west and south of the SDA (see Figure 2-4) into the sedimentary interbeds beneath the SDA. The last discharge to the spreading areas occurred in 1999, a year before the start of the advanced tensiometer monitoring. Monitoring wells, with nested advanced tensiometers that monitor a vertical profile, were installed in 2004 (Wells 1935 and 1936) to fully evaluate the influence of lateral flow from the spreading areas to depths of 117 m (385 ft). It is theorized that water in the sediments and basalt above the perched layer immediately above the C-D interbed is only affected by infiltration near the SDA and not by water that has moved laterally from recharge at the spreading areas.

Fourteen of the 25 deep locations continued to indicate steady-state conditions (see Figure 4-4), as identified in the 2000 through August 2002 data (McElroy and Hubbell 2003). Fiscal Year 2004 water potentials were stable in basalt at Wells 772-90, 765-80, 765-97, I2D-176, O3-88, and O7-241; in the B-C sedimentary interbed (see Figure 4-5) at Wells 765-103, I1S-103, I2S-94, O2-107, O5-105, and O7-121; and in the C-D sedimentary interbed (see Figure 4-6) at Wells I2D-223 and O3-221. The slow rise in water-potential values at Wells O2-107 and O7-241 is indicative of air entry into the tensiometer. Refilling the water chamber with water returned the measurements to near the initial readings. Two locations with small water potential changes (i.e., Well O2-107, with an increasing trend, and Well 765-103, with a decreasing trend) may be showing long-term changes in water potential with slopes that are twice those in the steady-state tensiometers. Sites I2S and D, O3S and D, and O-7S and D show steady-state conditions at each depth in the vertical profile.

Two tensiometers (i.e., at Wells O1-97 and O4-226) showed gradual wetting trends over the monitoring period. The tensiometer at Well O1-97 indicates a slow (approximately 40 cm of water) rise in water potentials in the B-C interbed since spring 2001. In the C-D interbed, at Well O4-227 (see Figure 4-7), water potentials have risen consistently over the monitoring period; however, this rise appears to be leveling off, with a total rise of approximately 100 cm of water. The decrease in water potentials at Well O4-110 occurred over the same time as the wetting of sediments in the deeper C-D interbed (Well O4-227) at the same well and is probably related, with moisture drainage occurring in the overlying B-C interbed toward the C-D interbed.

Wells I1S-103 and I1D-103 are additional sites with different trends in water potential at the two depths. Well I1S-103 shows a steady trend near -30 cm, while Well I1D-227 shows a decreasing trend from -250 cm to nearly -400 cm. Table 3-4 shows that Wells O-4 and 76-5 both have large decreases in water potential in the upper tensiometers and little-to-no changes at the deepest tensiometer. This indicates water drainage from the upper portion of the vertical profile that has not reached the lower tensiometer.

In addition to the long-term trends in water-potential data, some tensiometers indicate small water potential increases over portions of the year. Figure 4-8 shows water potential data from six of the more responsive advanced tensiometers. The changes in water potentials may be the result of barometric pressure influences or possibly recharge.

Four of the new wells (1935, 1936, 2004 and 2006) produced data during FY 2004. Well 1935 indicates interbeds at about 12 and 85 m (40 and 280 ft) deep; these interbeds have some of the lowest water potentials measured in this well. The two driest readings, at depths of 72 and 76 m (237 and 250 ft) are outside of the tensiometeric range. The instruments may be backfilled adjacent to bentonite (the sealing material placed between the instruments) or may represent very dry conditions at those depths. The low water potentials at the shallowest instrument depth (12.5 m [41 ft]) suggest that surface sediments may be dry from evapotranspiration.

Well 1936 has interbeds at depths of 9, 34, and 73 m (30, 110, and 240 ft). Similar to Well 1935, the wettest depths are recorded in fractured basalts at 83 and 105 m (272 and 344 ft), while the three sedimentary interbeds are some of the driest materials measured in this well.

Well 2004 has interbeds at depths of 22, 30, and 73 m (73, 100, and 240 ft). Data from an advanced tensiometer at the surficial sediment basalt are not shown, because the data indicate that conditions are too dry for the instrument to measure water potentials. This may be due to instrument contact with bentonite used for the well completion or dry sediments at this location.

Well 2006 has interbeds at depths of 34 and 73 m (110 and 240 ft); there is no thin interbed at 22 m (73 ft) bls as seen in Well 2004. The deeper instrument (i.e., 237 ft) is nearly outside the range of the tensiometers. It may be in contact with bentonite used in the backfill process. Data from an advanced tensiometer at the surficial sediment basalt are not shown, because the data indicate that conditions are too dry for the instrument to measure water potentials. This may be due to instrument contact with bentonite used for the well completion or dry sediments at this location.

5. DATA AND ANALYSIS OF PERCHED WATER MONITORING

Water level data is collected from six deep-perched, water-monitoring wells and seven neutron access tubes installed in surficial sediments in the SDA (see Figure 2-3). These instruments monitor for the presence of perched water and its depth at locations where perched water has been observed during previous investigations. Perched water is monitored to provide data on fast flow paths in the deep vadose zone and to monitor "moist" areas within the SDA. Perched water has been present for extended periods in several deep wells, while other wells have only detected standing water periodically. Shallow perched water in the surficial sediments is typically detected for short time periods in the spring and is associated with snowmelt and runoff in the disposal area and, periodically, in response to large precipitation events. In February 2003, dataloggers and pressure sensors[e] were placed in the deep perched water wells and shallow neutron access tubes to obtain continuous water-level measurements. Water levels are measured hourly, and dataloggers are downloaded monthly.

5.1 Deep Vadose Zone Perched Monitoring

The water levels in six deep vadose zone perched water-monitoring wells were recorded during portions of FY 2004 (see Figure 3-5). The water level data indicate changes in the thickness of the perched water layers, providing evidence of changes in flux to these perched water bodies. The plotted data accurately show the changes in the water levels while the depth may vary from the absolute depth of water. The dataloggers need to be referenced to a known water level in the field to correct the absolute depths of water for these data. Deeper perched water wells were drilled for various projects, and when perched water was suspected, the wells were completed at that point to allow water-level measurement in the perching layer.

The water level in Well 9V indicates a pressure decrease of about 3 m (9 ft) of water from March to October 2004. Previous monitoring detected only a very thin layer or that no water was present in the well. Monitoring in the 1990s was intermittent and relied on dataloggers and periodic E-line manual measurements. This decreasing water level indicates that deep-perched water layers can form in the subsurface at locations where only thin layers of perched water had been detected previously.

The data from Well 8802 in September through November 2003 was collected with an older datalogger that was corrected to an absolute water level. The water level indicates about 40 cm of water, which has a double peak (that may be related to a changing barometric pressure or changes in moisture flow) and then shows a decline in water level in FY 2003. A new datalogger was placed in the well. Then data indicated a nearly level water level with small amplitude water level fluctuations, similar to that seen previously. Well USGS 92 shows a muted trend similar to that in Well 8802.

The remaining three wells show no change in water levels over the period of record (i.e., see Figure 5-1). Manual water level measurements were not obtained over this monitoring period from any of these sites. Water levels were measured in Wells D10 and 10V previously; it is believed that this shows that water levels did not change over this time period (i.e., FY 2004). Well 9302 has not shown perched water in the past few years; therefore, the level trend indicates a lack of perched water over this time. As noted previously, data presented in this table are correct for trends but not for absolute water depth.

[e] Instruments are from Electronic Engineering Innovations, Las Cruces, New Mexico.

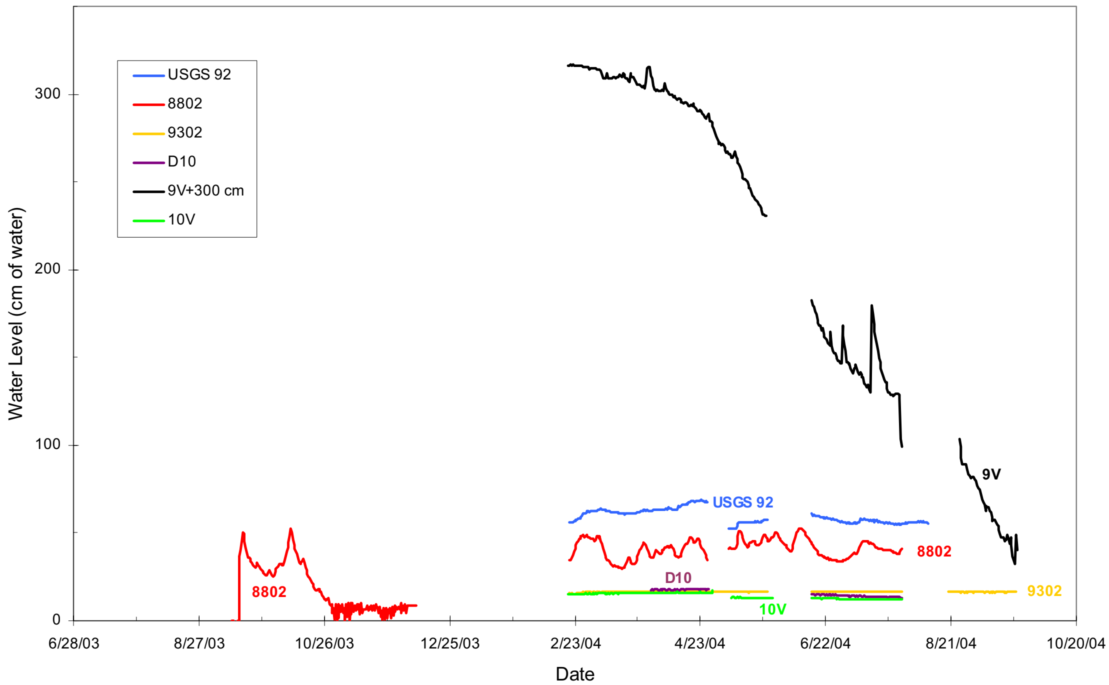


Figure 5-1. Water level trend data from deep-perched water wells in the Subsurface Disposal Area. Note that trends are correct, but the sensors have not been set to an absolute (zero offset) reference level.

5.2 Perched Water Monitoring in the Surficial Sediments

Locations of the shallow neutron access tubes are shown in Figure 3-5. The shallow moisture-monitoring access tubes were installed between pits and trenches and in areas of interest identified during several projects that date from the 1960s to the mid-1990s. These neutron access tubes were designed to allow access for neutron moisture monitoring through the walls of the tubing, but were not capped on the bottom and so are monitored for the formation of perched water at the surficial sediment/basalt contact.

Occasionally, perched water forms in the surficial sediments on the basalt. The water is transitory, lasting a few days or weeks at most. Perched water data from all of the access tubes for FY 2004 are presented in Figure 5-2. NAT-11 and -13 show the formation of perched water in March and September 2004, respectively. NAT-13 data indicated perched water formation following snowmelt (see Figure 5-3). Perched standing water was detected on March 13, 2004, to a depth of about 120 cm (47 in.), and then drained out over the next few days. The water level data show several rapid increases and decreases in the water level that indicates the formation of perched water in this well. The rapid oscillations cannot be explained without testing the loggers, but might be associated with water travel around the exterior of the casing. This had been suspected in the past, so bentonite was placed around the neutron access tube's annular space at land surface. This is a site that accumulates moisture at land surface and has shown perched water previously. NAT-11 indicated the formation of perched water in September 2004 that has a similar drainage trend to that seen in NAT-13 (Figure 5-4). Small amounts of perched water appear to have developed in NAT-6, -12, and -13 following a June rainstorm (Appendix C) while no perched water was detected in MS-02, -03, and -04.

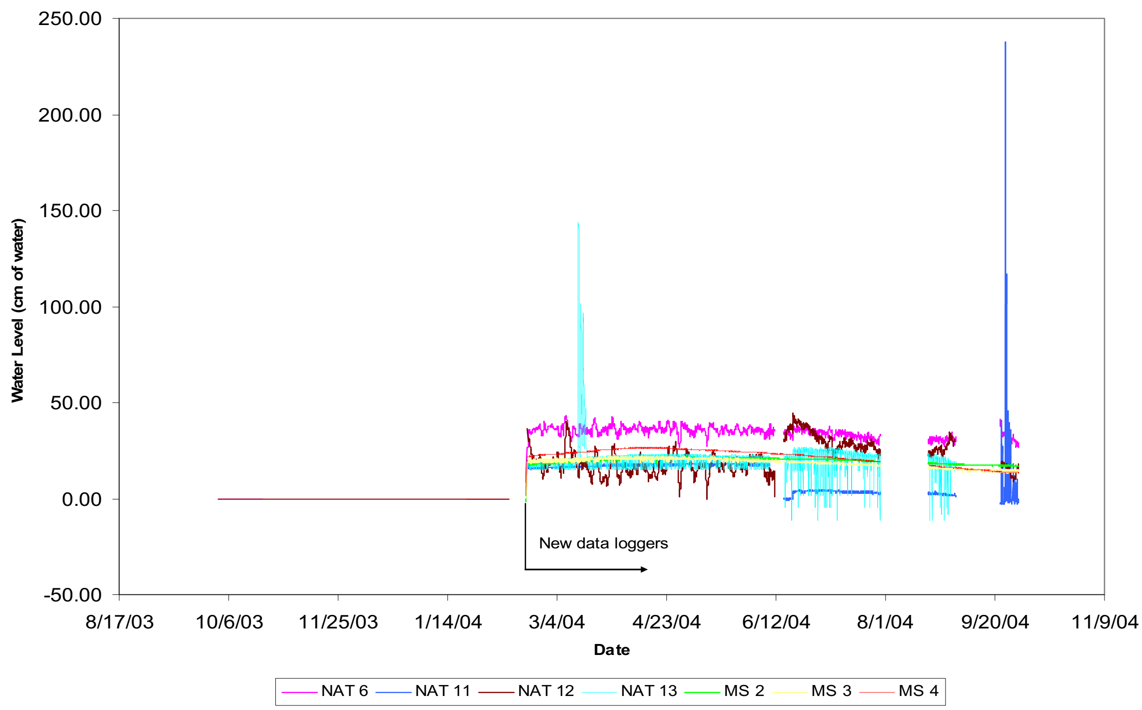


Figure 5-2. Monitoring of water level data at the surficial sediment basalt contact. NAT-11 and 13 indicate formation of standing water in access tubes. Note that trends are correct, but the sensors were not set to an absolute (zero offset) reference level.

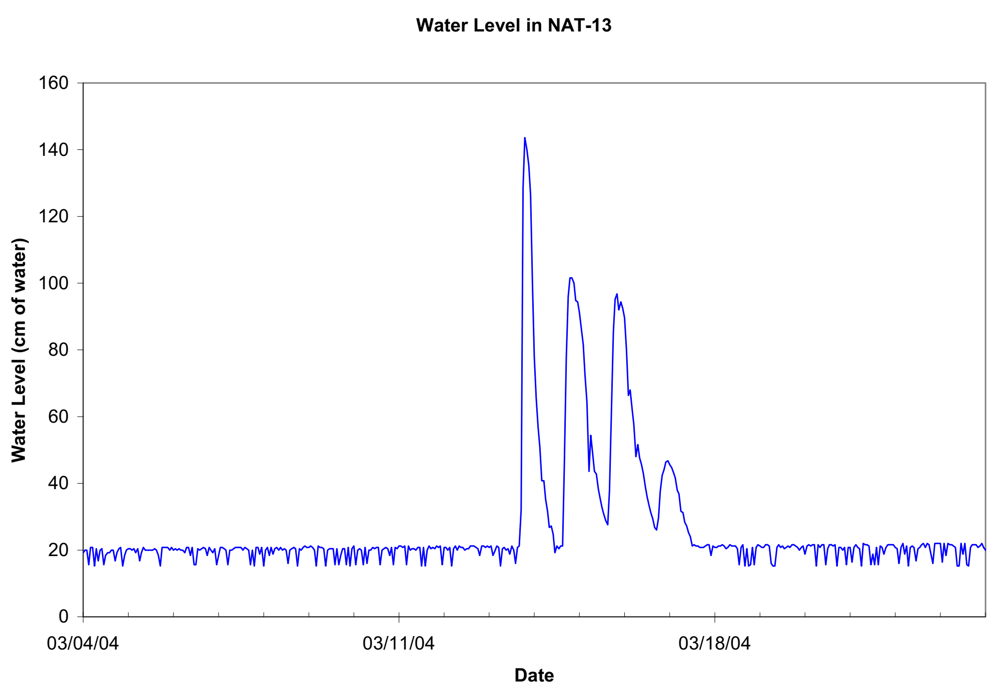


Figure 5-3. Formation of perched water in NAT-13 on March 13, 2004.

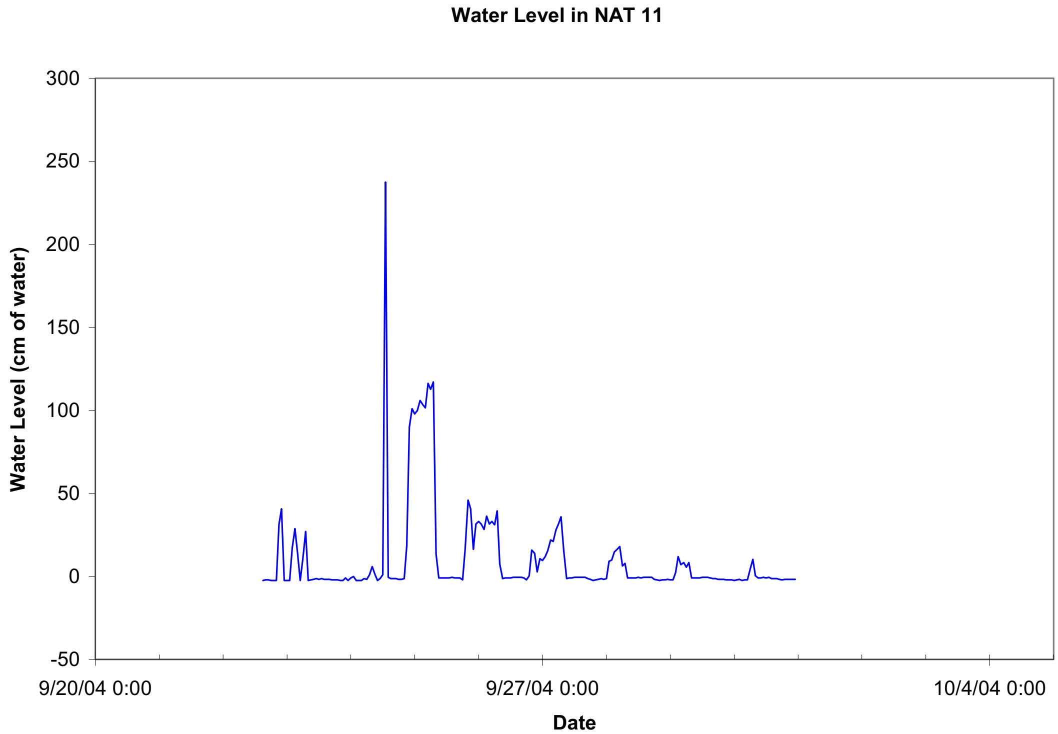


Figure 5-4. Water levels measured in NAT-11, September 2004.

Table 5-1. Perched water measured in the shallow vadose zone for Fiscal Year 2004.

Measurement Location	Perched Water in Fiscal Year 2004	Date of Perched Water
NAT-6	Yes	June 19, 2004
NAT-11	Yes	June 19 and September 24, 2004
NAT-12	Yes	June 19, 2004
NAT-13	Yes	March 14 and June 19, 2004
MS-02	No	Not applicable
MS-03	No	Not applicable
MS-04	No	Not applicable

The occurrence of shallow perched water in June 2004 follows the heaviest precipitation event at RWMC in FY 2004 (see Figure 5-5). On June 18, 2004, 1.62 cm (0.64 in.) of rainfall was measured (the total for FY 2004 was 13.7 cm [5.4 in.]). An additional 0.13 cm (0.06 in.) fell the following day.

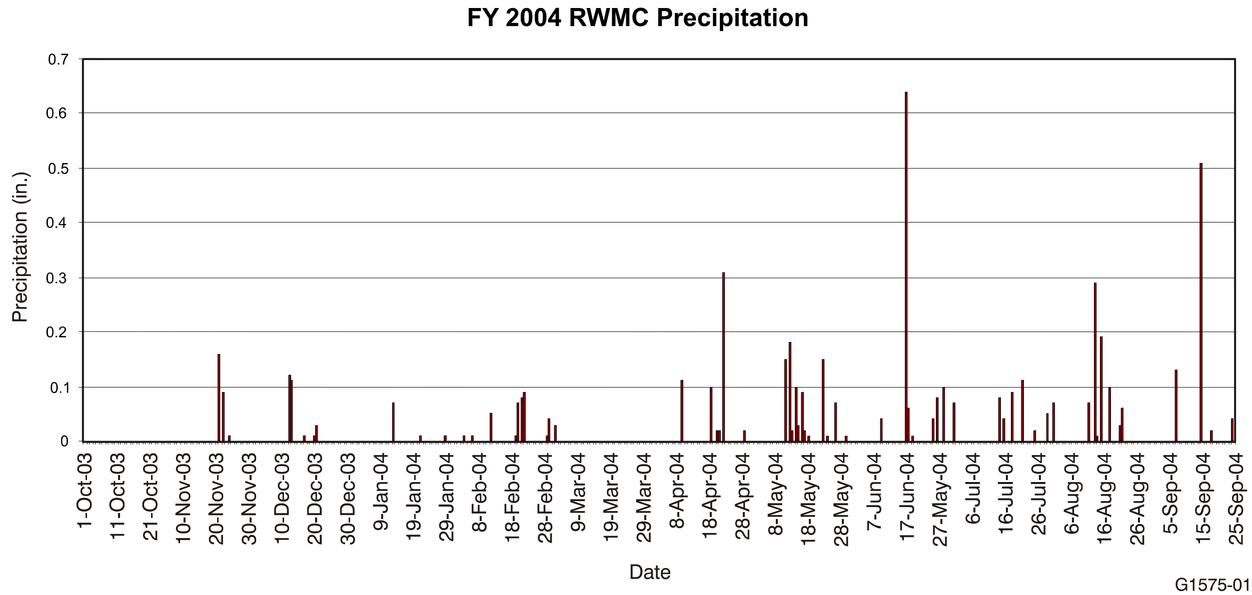


Figure 5-5. Precipitation measured by the National Oceanic and Atmospheric Administration at the Radioactive Waste Management Complex during Fiscal Year 2004.

6. DATA AND ANALYSIS OF SOIL-MOISTURE, RESISTIVITY, AND TEMPERATURE AND DIRECT-PUSH TYPE B TENSIOMETER MONITORING IN SURFICIAL SEDIMENT MONITORING

In this section, data and analysis of FY 2004 SMR and DPT monitoring are presented by focus area. The following paragraphs describe the methodology used in analyzing the data from SMR and DPT measurements.

Ideally, the rise and fall of the temporal SMR data reflect changes in volumetric moisture content, whereas a flat trend line indicates no change in moisture content. However, some of the SMR sensors appear to be affected by soil temperature, resulting in trend lines that more or less parallel the cyclic or sinusoidal temperature trend (Figure 6-1) (Myers et al. 2005). Individual temperature corrections for a number of sensors were provided by Applied Research Associates, who manufactured the SMR sensors. These corrections were applied to data from 1/1/2004 forward for sensors listed in Appendix D, Table D-1. Appendix D presents those temperature corrections. Since the correlation between temperature and SMR output can be positive or negative and it varies in magnitude by sensor, this data cannot be used for determining moisture content variation over annual cycles. However, despite the corrections, the cyclic nature of the moisture data remains in most cases despite the temperature correction, and it is not clear if the remaining sinusoidal trends are representative of infiltration and drainage. For this reason, the cyclic, gradually increasing and decreasing moisture contents are not analyzed.

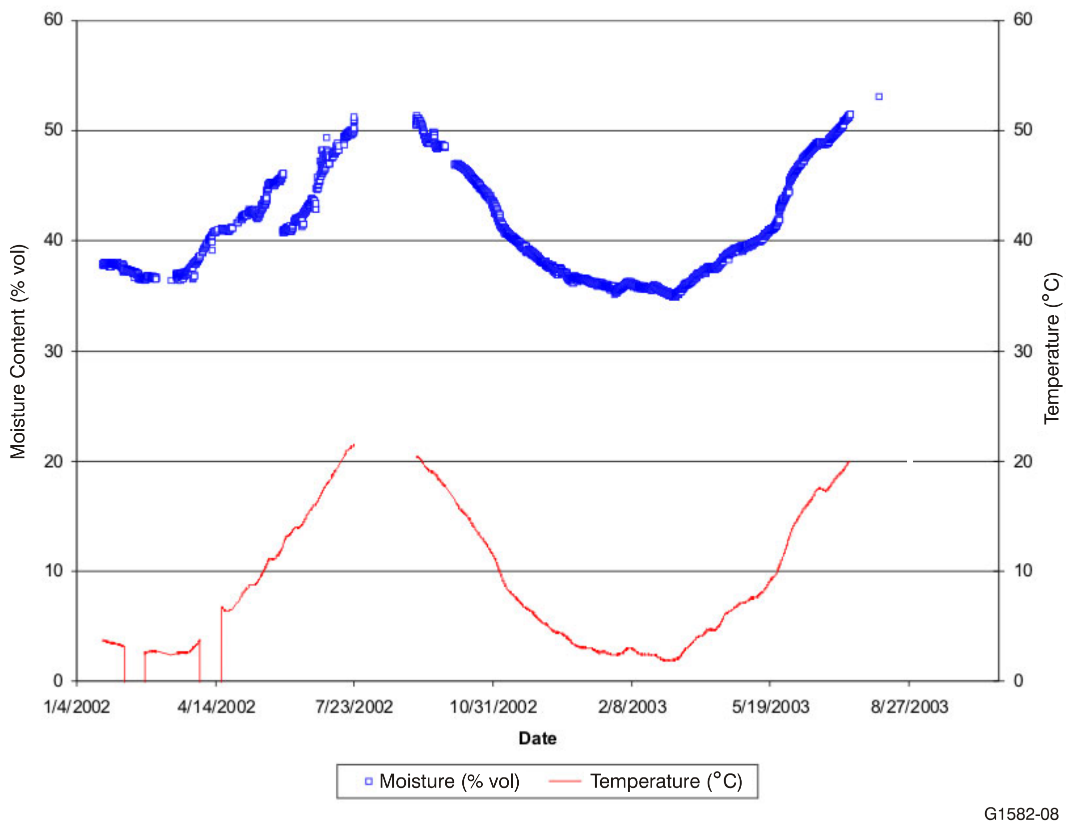


Figure 6-1. Plot showing sinusoidal trend of moisture content data (Sensor 245) that mimics the temperature trend (from Myers et al. 2005).

Only specific, individual wetting events are identified as infiltration in this document. These wetting events can be identified in both temperature-corrected and uncorrected data. For purposes of this report, a wetting event is characterized by a rise in moisture content followed several days or weeks later by a falling off of the moisture content as the soil dries. Figure 6-2 is one example of a moisture event in response to snowmelt. Its shape indicates a gradual (several days) wetting and drying of the soil.

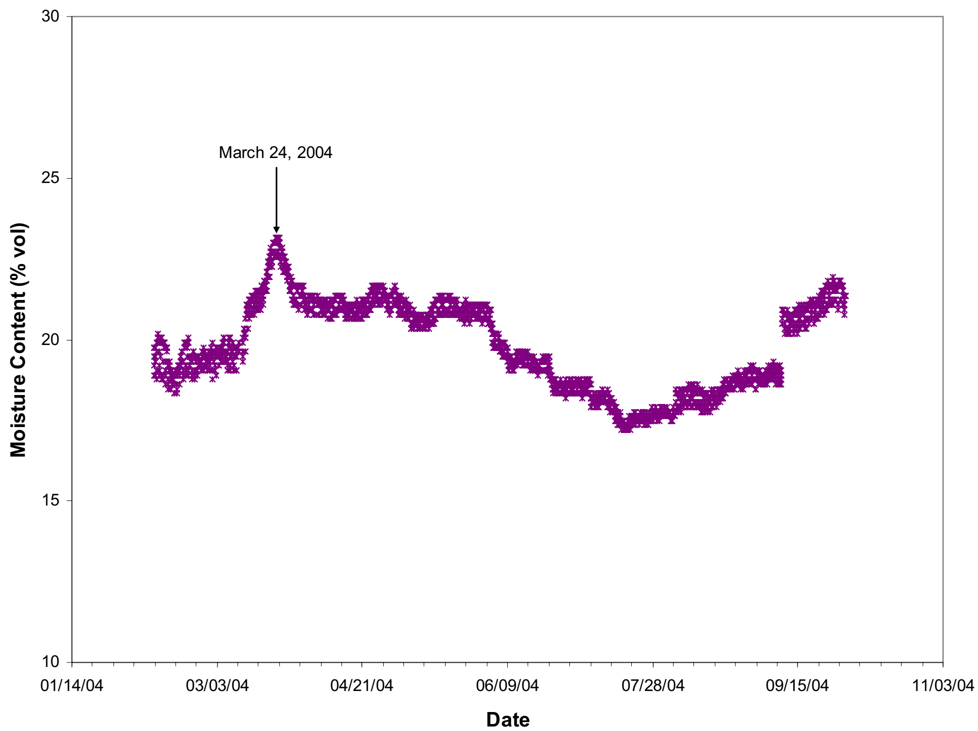


Figure 6-2. Plot showing a moisture event at 2.8 ft below land surface observed on March 24, 2004, in the Pit 5-4 cluster.

Data jumps, as shown in Figure 6-3, may indicate an instrument or datalogger problem, or a problem with water moving down the probe casing. In either of these cases, the jumps in data probably do not reflect infiltration or drainage through the soils, but are an artifact of the instrumentation. Therefore, data jumps will not be included in the infiltration analyses. Moisture data that remain flat are considered representative, and indicate no change in moisture content.

The DPT data are used to indicate the water potential above, within, and below the waste and the long-term water potential trends. A typical water potential response to a moisture event is usually indicated by a trend line that moves upward toward increasing water potential (less negative water potential indicating wetting) followed by a decrease in the water potential (more negative water potential indicating drying). Tensiometers require water in the lower water reservoir to obtain representative readings of soil-water potential. If the sensor runs out of water, such as if the soil-water potential exceeds that which can be read by a tensiometer, then the readings will revert to reading atmospheric pressure.

Plots of the SMR data, from January 2004 through September 2004, are presented in Appendix A. The DPT data for FY 2004 are presented in Appendix B. Several SMRs and DPTs have been removed for the construction activities associated with the Accelerated Retrieval Project. These instruments are noted in the following subsections.

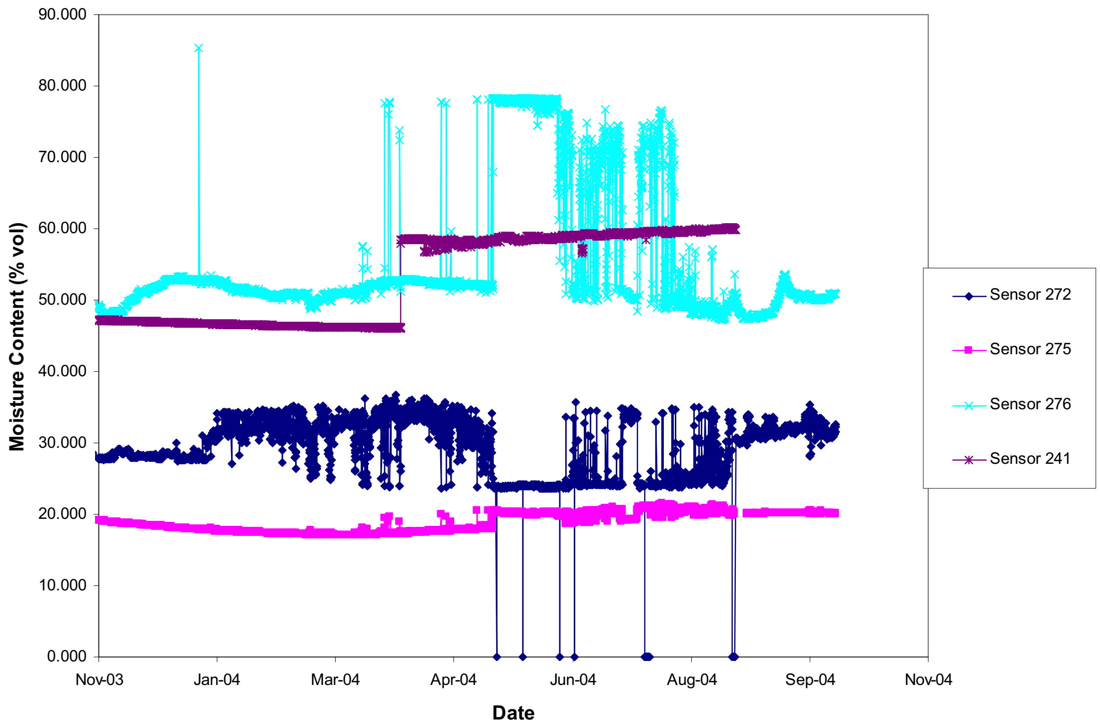


Figure 6-3. Jumps in data from early May to August that may be caused by an instrument or datalogger malfunction, or a problem with water moving down the probe casing.

6.1 Uranium/Enriched Uranium Focus Area (Pit 5)

The Uranium/Enriched Uranium Focus Area was established to investigate waste that originated at the Rocky Flats Plant and that contained highly enriched uranium or significant sources of Pu-239.

6.1.1 Soil-Moisture, Resistivity, and Temperature Monitoring

Seven SMR sensors in the Pit 5 Uranium/Enriched Uranium Focus Area collected data in FY 2004. Table 6-1 lists the seven working SMR sensors, individual sensor depths, data collection information, whether temperature corrections were applied to the data, and whether wetting events were observed in the data plots. Moisture contents are plotted in Appendix A, Figure A-1.

Soil-moisture data suggest an infiltration event occurred at the 0.85-m (2.8-ft) depth in Pit 5-4, Sensor 289, in early March (Figure 6-2). A wetting event was not noted at the 2.5-m (8.2-ft) or 3.11-m (10.2-ft) sensors (i.e., 279 and 285), located on the same probe. Little-to-no change in moisture content was seen at these two sensors over the data intervals shown. Moisture contents showing cyclic trends or data jumps were not interpreted.

6.1.2 Direct-push Type B Tensiometer Monitoring

No DPTs are installed in the Uranium/Enriched Uranium Focus Area.

Table 6-1. Uranium/Enriched Uranium Focus Area working soil-moisture sensors, depths, data collection, temperature corrections, and monitored wetting events for Fiscal Year 2004.

Focus Area Cluster	Sensor Identification Number	Depth (ft)	Moisture Data	Temperature Correction Applied	Wetting Event
Pit 5-TW1	290	2.9	Yes, from early June 2004	Yes	No
Pit 5-TW1	282	10.2	Yes, from early June 2004	No	No
Pit 5-4	289	2.8	Yes	No	Yes, in March
Pit 5-4	279	8.2	Yes, from late May 2004	Yes	No
Pit 5-4	285	10.2	Yes	No	No
Pit 5-UMU	2A2	3.0	Yes	Yes	No
Pit 5-UMU	2B1	4.3	Yes	No	No

6.2 High Plutonium Density Focus Area (Pit 6)

The Pit 6 High Plutonium Density Focus Area was established to collect moisture data at the Rocky Flats Plant drum disposal site suspected of containing significant sources of plutonium contaminated waste.

6.2.1 Soil-Moisture, Resistivity, and Temperature Monitoring

Two SMR sensors in the High Plutonium Density Focus Area collected data the last month of FY 2004. Table 6-2 lists the two working sensors, individual sensor depths, data collection information, whether temperature corrections were applied to the data, and whether wetting events were observed in the data plots. Moisture contents are plotted in Appendix A, Figure A-2.

Table 6-2. Pit 6 High Plutonium Density Focus Area working soil-moisture sensors, depths, data collection, temperature corrections, and monitored wetting events for Fiscal Year 2004.

Focus Area Cluster	Sensor Identification Number	Depth (ft)	Moisture Data	Temperature Correction Applied	Wetting Event
P6-PU-M	2A3	3.9	Yes, one month (September 2004)	Yes	Yes, September 21, 2005
P6-PU-M	2A4	14.5	Yes, one month (September 2004)	Yes	No

Although the data are limited and exhibit some scatter, the SMR sensor 2A3, at the 1.19-m (3.9-ft) depth, indicates an infiltration event on September 21, 2005, after 1.3 cm (0.51 in.) of precipitation fell the previous day. A corresponding wetting event was not exhibited at the 4.5-m (14.8-ft) depth.

6.2.2 Direct-push Type B Tensiometer Monitoring

No DPT instruments are monitoring the Pit 6 High Plutonium Density Focus Area.

6.3 Depleted Uranium Focus Area (Pit 10)

The objective for monitoring at the Depleted Uranium Focus Area was to characterize moisture movement and determine whether there is a potential for solute transport of leached uranium and organics from the Rocky Flats Plant waste disposals in the west end of Pit 10. The area is surrounded on several sides by runoff ditches.

6.3.1 Soil-Moisture, Resistivity, and Temperature Monitoring

Three clusters of instruments (i.e., Clusters DU-08, DU-10, and DU-14) are in the Depleted Uranium Focus Area. Thirteen of these SMR sensors collected moisture-content data for FY 2004 and are listed in Table 6-3. Moisture contents are plotted in Appendix A, Figures A-3 and A-4.

Table 6-3. Depleted Uranium Focus Area working soil-moisture sensors, depths, data collection, temperature corrections, and monitored wetting events for Fiscal Year 2004.

Focus Area Cluster	Sensor Identification Number	Depth (ft)	Moisture Data	Temperature Correction Applied	Wetting Event
DU-08-M1	269	11.5	Yes	Yes	No
DU-08-M2	299	6	Yes	Yes	No
DU-08-M2	298	12.1	Yes	Yes	No
DU-08-M2	2A0 (100)[a]	18.6	Yes	No	No
DU-10-M	296	5.5	Yes	No	No
DU-10-M	277	6.7	Yes	Yes	No
DU-10-M3	263	4	Yes	No	No
DU-10-M2	271	6.6	Yes	Yes	No
DU-10-M1	264	9.2	Yes	No	No
DU-14-M1	280	4.5	Yes	Yes	No
DU-14-M1	278	9.8	Yes	Yes	No
DU-14-M1	276	15.2	Yes	No	Yes, August and September 2004
DU-14-M2	297	12	Yes	Yes	Yes, August and September 2004

a. ( ) is alias sensor name.

Moisture content data for Sensors 297 and 276, at the 3.7-m (12.1-ft) and 4.6-m (15.2-ft) depths, respectively, indicate wetting events in August and again in September. The depth and extremely low moisture contents from Sensor 297 suggest this sensor is located in the waste zone. Sensor 276 was installed in the sediment underlying waste. These data suggest water infiltrated into the waste zone at DU-14-M2 and into the sediment underlying the waste at DU-14-M1. However, a clear pattern of downward infiltration was not observed in the sensors above the 4.5-m (15.2-ft) depth in DU-14-M1. It is possible water moved into the sediments at this location (Probe DU-14-M1) laterally along the top of the basalt, since the sensors above this depth did not document an infiltration response. Lateral transport of magnesium chloride in the surficial sediments has been documented to extended distances of up to 40 ft (Hull and Bishop 2003).

Little-to-no moisture content change was noted at the 3.5-m (11.5-ft) depth at DU-08-M1 (Sensor 269) and the 3.0-m (9.8-ft) depth at DU-14-M1 (Sensor 278). The data jumps at Sensors 271, 280, 299, and 276 (in May, for example) and the cyclic data were not analyzed.

6.3.2 Direct-push Type B Tensiometer Monitoring

Nine DPTs are installed in the Depleted Uranium Focus Area in three clusters, with three collecting water-potential data over portions of the year: Cluster DU-08 (Sensor T3) and Cluster DU-10 (Sensors T2 and T3). Table 6-4 provides depth information for the functioning tensiometers. Water potential and soil gas pressure data are plotted in Appendix B, Figures B-5, B-6, and B-7.

DU-08 Tensiometer T3 indicated the water potential was greater than -250 cm (dryer), but the sensor ran out of water before the water potential reached equilibrium with the surrounding sediments. DU-10 Tensiometer T2 provided data in fall 2003 of about -300 cm water potential with an increase in water potential to -250 cm, indicating a wetting event. The instrument was refilled in June, indicating about -250 cm for several months until it ran out of water. The response in June suggests the instrument was initially drying to below -350 cm, but then wet to about -300 cm. DU-10 Tensiometer T3, located about 2.5 ft deeper, has continuous data that indicated a drying trend to mid-June (-450 cm) and then following being refilled, the water potential increased to about -250 cm, indicating recharge to the instrument located beneath the waste. Thus, both tensiometers indicate a wetting trend within and below the waste at this location in the June time period. The water potential was about the same at both depths in fall 2003, but the June wetting event raised the water potentials in both with the lower instrument, below the waste, having a higher water potential (wetter). They then both indicate gradual drying (evaporation or gravity drainage) to the end of the fiscal year.

Table 6-4. Direct-push Type B tensiometer instrumentation installed in the Depleted Uranium Focus Area in Fiscal Year 2004.

Focus Area Cluster	Tensiometer	Depth (ft)	Water Potential (cm of water)	Water Potential Trend
DU-08	T3	16.4	less than -250	Did not equilibrate[a]
DU-10	T2	6.7	-350	Wetting in June, then drying through September
DU-10	T3	9.1	-200 to -450	Decreasing trend to June, wetting through August followed by steady reading

a. "Did not equilibrate" = Water potential is less than indicated (dryer).

6.4 Americium/Neptunium Focus Area (Pit 10)

The objective for monitoring moisture in the Americium/Neptunium Focus Area is to characterize moisture movement in the waste stream that contains Am-241.

6.4.1 Soil-Moisture, Resistivity, and Temperature Monitoring

Three SMR sensors in the Americium/Neptunium Focus Area collected moisture-content data for FY 2004 and are listed in Table 6-5. Moisture contents are plotted in Appendix A, Figure A-5.

No wetting events were observed over the short, one-month data set for each of these sensors.

Table 6-5. Americium/Neptunium Focus Area working soil-moisture sensors, depths, data collection, temperature corrections, and monitored wetting events for Fiscal Year 2004.

Focus Area Cluster	Sensor Identification Number	Depth (ft)	Moisture Data	Temperature Correction Applied	Wetting Event
741-08-M1	267	4.1	Yes, September 2004	No	No
741-08-M1	268	11.5	Yes, September 2004	No	No
741-08-M1	266	19.9	Yes, September 2004	No	No

6.4.2 Direct-push Type B Tensiometer Monitoring

Table 6-6 provides monitoring results for the functioning DPT in the Americium/Neptunium Focus Area. This area's water potential and soil gas plots are plotted in Appendix B, Figure B-1. The DPT data in 741-08 T3 indicates that the water potential exceeds -250 cm (it is dryer than -250 cm), but the instrument ran out of water before the instrument equilibrated with the surrounding sediment.

Table 6-6. Direct-push Type B tensiometer instrumentation installed in the Americium/Neptunium Focus Area in Fiscal Year 2004.

Focus Area Cluster	Tensiometer	Depth (ft)	Water Potential (cm of water)	Water Potential Trend
741-08	T3	19.9	less than -250	Did not equilibrate[a]

a. "Did not equilibrate" = Water potential is less than indicated (dryer).

6.5 Moisture-Monitoring Network (Pits 4 and 6)

This network was established to evaluate the impact that water-collection ditches paralleling roadways have on wetting of the surficial sediments. These ditches are known to collect runoff water following snowmelt and rainstorms.

6.5.1 Soil-Moisture, Resistivity, and Temperature Monitoring

Twenty-seven SMR sensors in the Moisture-Monitoring Network (Pits 4 and 6) collected moisture-content data for FY 2004 and are listed in Table 6-7. Moisture contents are plotted in Appendix A, Figures A-6, A-7, A-8, and A-9.

Shallow wetting events were observed at these moisture-monitoring network sites. SMR data indicate that wetting events occurred at the MM2-3 probe (Sensors 246 and 215) at the 0.5- and 0.9-m (1.7- and 3.0-ft) depths; MM4-3C (Sensor 255) at the 1.5-m (4.8-ft) depth; and MM4-4B (Sensor 257) at the 1.3-m (4.2-ft) depth. Data at the 1.2-m (4.0-ft), 3.7-m (12.1-ft), and 4.2-m (13.8-ft) depths for Sensors 216, 273, and 244 at probes MM3-2, MM4-2B, and MM3-3, respectively, showed little-to-no change in moisture content. The data jumps and more cyclic data were not analyzed.

Table 6-7. Moisture-Monitoring Network (Pits 4 and 6) working soil-moisture sensors, depths, data collection, temperature corrections, and monitored wetting events for Fiscal Year 2004.

Focus Area Cluster	Probe Identification Number	Depth (ft)	Moisture Data	Temperature Correction Applied	Wetting Event
MM2-1	241	12.5	Yes, until mid-August 2004	No	No
MM2-1	231	16	Yes, until mid-August 2004	No	No
MM2-2	222	9.1	Yes	No	No
MM2-2	224	10.8	Yes		No
MM2-3	246	1.7	Yes, until August 2004	No	Yes, April 2004
MM2-3	215	3	Yes, until August 2004	No	Yes, April 2004
MM3-1	245	4.5	Yes	No	Too noisy to analyze
MM3-1	253	7.6	Yes, until mid-August 2004	No	No
MM3-1	242	9.7	Yes, June through August	No	No
MM3-2	216	4	Yes, since mid-July 2004	No	No
MM3-2	252	7	Yes, since June 3, 2004	No	No
MM3-2	210	8.2	Yes, since June 3, 2004	No	No
MM3-3	254	7.5	Yes, since June 3, 2004	No	No
MM3-3	244	13.8	Yes, since	No	No

Table 6-7. (continued).

Focus Area Cluster	Probe Identification Number	Depth (ft)	Moisture Data	Temperature Correction Applied	Wetting Event
			June 3, 2004		
MM3-3	225	17	Yes, since June 3, 2004	No	No
MM4-1B	287	6.3	Yes	No	No
MM4-1B	286	14.7	Yes	No	No
MM4-2B	275[a]	4.7	Yes	Yes	No
MM4-2B	273	12.1	Yes	No	No
MM4-3	243	6.2	Yes	No	No
MM4-3	218	9.1	Yes	No	No
MM4-3C	255	4.8	Yes	No	Yes, May 2004
MM4-1D	272[a]	16.72	Yes	Yes	No
MM4-4B	257	4.2	Yes	Yes	Yes, early May
MM4-4B	256	8.7	Yes	No	No
MM4-5	234	13.9	Yes	No	No
MM4-5B	239	9.8	Yes	No	No

a. Data for Sensors 272 and 275 are shown in Figure 6-3.

6.5.2 Direct-push Type B Tensiometer Monitoring

Twenty-three of the 39 DPTs installed in the Moisture-Monitoring Network function and provided water potential data. Data are plotted in Appendix B, Figures B-8 through B-20. Nine of these functioning instruments appear too dry to operate and are noted to have water potentials with the < symbol and trends that did not reach equilibration. The indicated water potential refers to the minimum reading before the sensor reverted to measuring the soil gas pressure. The remaining fourteen sensors provide water potential data over portions of the year as well at trend data (i.e., wetting, drying, or a combination).

Seven tensiometers at the intermediate depths (i.e., within waste—T2) indicated water potentials from -50 to -500 cm, while the seven lowest depth instruments ranged from near saturation (0) to -450 cm (Table 6-8). The intermediate depth sensors showed two that were drying, three with steady readings, one wetting, and one that showed drying until August followed by two wetting events that then stabilized. The deeper depths (i.e., below waste—T3) indicated five tensiometers were wetting: one with steady readings and one that was indeterminate since it had just equilibrated at the end of the year (Appendix B, Figure B-19). There were no shallow instruments above the waste (i.e., T1) that provided equilibrated water potential data or data trends. This response is related to difficulty in maintaining shallow instruments in dry sediments.

Figure 3-7 shows the sensors for Cluster MM4-4, Tensiometer T3, coming to equilibrium after being serviced in June 2004. This is a typical response for a functioning tensiometer.

Table 6-8. Fiscal Year 2004 monitoring results for the direct-push Type B tensiometer instrumentation installed in the Moisture-Monitoring Network Focus Area.

Focus Area Cluster	Direct-push Type B Tensiometer	Depth (ft)	Water Potential (cm of water)	Water Potential Trend
MM1-1	T2	10.5	less than -400	Did not equilibrate[a]
MM1-1	T3	17.7	less than -75	Did not equilibrate[a]
MM1-2	T2	9.3	less than -50	Did not equilibrate[a]
MM2-1	T2	11.9	-200	Slight wetting
MM2-1	T3	16.0	-150	Slight wetting
MM2-2	T2	8.6	less than -400	Did not equilibrate[a]
MM2-2	T3	9.2	less than -550	Did not equilibrate[a]
MM2-3	T2	5.1	-80	Steady
MM3-1	T3	9.7	-200 to -330	Drying to April, then wetting to end of year
MM3-2	T1	5.0	less than -50	Did not equilibrate[a]
MM3-2	T2	6.6	-450	Steady
MM3-2	T3	8.4	-150 to near saturation	Wetting
MM3-3	T2	4.6	less than -400 in fall 2003;-220 June through September 2004	Drying June through September
MM4-1	T1	5.7	less than -600 June, -400 September 2004	Did not equilibrate[a]
MM4-1	T2	14.9	-300	Steady
MM4-1	T3	18.5	-450	Steady
MM4-2	T1	4.9	less than -50	Did not equilibrate[a]
MM4-2	T2	11.4	-150 to -500	Drying to late July, wetting to mid-August, then steady wetting to the end of the year
MM4-2	T3	15.8	-300 to near saturation	Wetting after June
MM4-4	T2	8.2	less than -50	Did not equilibrate[a]
MM4-4	T3	9.5	-500	Equilibrated in late September, no trend
MM4-5	T2	9.7	-150 to -200	Drying August through September
MM4-5	T3	13.5	-250 to -150	Stable until June, then a gradual increase until September

a. “Did not equilibrate” = Water potential is less than indicated (dryer).

6.6 Organic Sludge Focus Area

The objective for establishing the Organic Sludge Focus Area was to characterize organic contaminants in the east end of Pit 4. Most of the SMRs installed in this focus area are concentrated in areas with high sludge disposals to characterize moisture movement and determine whether sufficient water is available to leach contaminants from the sludge.

6.6.1 Soil-Moisture, Resistivity, and Temperature Monitoring

Nine SMR sensors in the Organic Sludge Focus Area collected moisture-content data for FY 2004 and are listed in Table 6-9. Moisture contents are plotted in Appendix A, Figure A-10.

Data from SMR sensors installed in this focus area do not indicate an infiltration event occurred. Little-to-no change in moisture contents were observed at the 4.2- and 6.8-m (13.9- and 22.3-ft) depths at Probe 743-08-M1 (Sensors 250 and 251), and the 5.8-m (19.1-ft) depth at Probe 743-03-M1 (Sensor 237). The data jumps and the cyclic data were not analyzed.

Table 6-9. Organic Sludge Focus Area working soil-moisture sensors, depths, data collection, temperature corrections, and monitored wetting events for Fiscal Year 2004.

Focus Area Cluster	Sensor Identification Number	Depth (ft)	Moisture Data	Temperature Correction Applied	Wetting Event
743-03-M1	235	3.4	Yes	No	No
743-03-M1	237	19.1	Yes	No	No
743-03-M2	2A8	12.5	Yes	No	No
743-18-M1	217	6.5	Yes	—	No
743-08-M1	247	6.6	Yes	No	No
743-08-M1	250	13.9	Yes	No	No
743-08-M1	251	22.3	Yes	No	No
743-18-M2	2B0(210)[a]	8.2	Yes	No	No
748-18-M3	2A9	19.2	Yes	No	No

a. ( ) is alias sensor name.

6.6.2 Direct-push Type B Tensiometer Monitoring

Nine DPTs were installed in the subsurface in the Organic Sludge Focus Area, all of which were removed late in Calendar Year 2004 for construction activities. Three of the DPTs appeared to work with water potentials in the range of -250 to -450 cm. Two of the sites indicated wetting to 5-ft depths. Table 6-10 lists the FY 2004 monitoring results for functioning DPTs in the Organic Sludge Focus Area. Data are plotted in Appendix B, Figures B-2, B-3, and B-4.

Table 6-10. Fiscal Year 2004 monitoring results for direct-push Type B tensiometer sensor in the Organic Sludge Focus Area.

Focus Area Cluster	Direct-push Type B Tensiometer	Depth (ft)	Water Potential (cm of water)	Water Potential Trend
743-03	T1	5.3	less than -450	Wetting in June
743-03	T3	18.5	-250	Steady
743-18	T1	5.5	-450 to -350	Wetting in December

6.7 High Plutonium-Density Focus Area (Pit 2)

The Pit 2 High Plutonium-Density Focus Area was established to characterize the Rocky Flats Plant drum shipments and disposals containing graphite molds (a waste expected to contain significant plutonium source material).

6.7.1 Soil-Moisture, Resistivity, and Temperature Monitoring

Two SMR sensors in the High Plutonium-Density Focus Area collected moisture-content data for FY 2004 and are listed in Table 6-11. Moisture contents are plotted in Appendix A, Figure A-11. These two SMR sensors were installed on August 16, 2004.

No wetting events were monitored in the limited data set.

Table 6-11. High Plutonium-Density Focus Area working soil-moisture sensors, depths, data collection, temperature corrections, and monitored wetting events for Fiscal Year 2004.

Focus Area Cluster	Sensor Identification Number	Depth (ft)	Moisture Data	Temperature Correction Applied	Wetting Event
P2-PU	249	19	Yes, one month (since mid-September 2004)	No	No
P2-PU	262	19	No, about 10 days in September 2004	No	Too little data

6.7.2 Direct-push Type B Tensiometer Monitoring

No DPTs are installed at this location.

6.8 Liquid Waste Disposal Focus Area

The Liquid Waste Disposal Focus Area was established to study several liquid waste disposal targets in Trench 24 that originated from the Naval Reactors Facility at the INL Site.

6.8.1 Soil-Moisture, Resistivity, and Temperature Monitoring

Two SMR sensors in the Liquid Waste Disposal Focus Area collected moisture-content data for FY 2004 and are listed in Table 6-12. Two SMR sensors, one in each of two clusters, were installed on August 11, 2004: Cluster HAL2-M1 (i.e., Sensor 2A5) and Cluster HAL2-M2 (i.e., Sensor 2A7). Moisture contents are plotted in Appendix A, Figure A-12.

No wetting events were monitored in the limited (one-month) data set.

Table 6-12. Liquid Waste Disposal Focus Area working soil-moisture sensors, depths, data collection, temperature corrections, and monitored wetting events for Fiscal Year 2004.

Focus Area Cluster	Sensor Identification Number	Depth (ft)	Moisture Data	Temperature Correction Applied	Wetting Event
HAL2-M1	2A5	20.4	Yes, since mid-September 2004	Yes	No
HAL2-M2	2A7	20.8	Yes, since mid-September 2004	No	No

6.8.2 Direct-push Type B Tensiometer Monitoring

No DPT sensors were installed at this location.

6.9 Activated Stainless Steel Investigation Focus Area (at SVR 12)

The Activated Stainless Steel Investigation Focus Area was established to learn more about C-14 releases (i.e., rates, locations, and quantities) associated with the irradiated reactor structural components in SVR 12.

Originally, two strings of SMR sensors were installed the Activated Stainless Steel Investigation Focus Area: Cluster SVR-12-MB (i.e., Sensors 281 and 283) and Cluster SRV-12-M (i.e., Sensor 284). The SMR and DPT instrumentation in the SRV-12-M cluster array was abandoned on May 20, 2004. Three DPTs were installed in this focus area.

6.9.1 Soil-Moisture, Resistivity, and Temperature Monitoring

Three SMR sensors in the Activated Stainless Steel Focus Area collected moisture-content data for FY 2004 and are listed in Table 6-13. One of the sensors, SVR-12-M (284), was discontinued in June 2004. Moisture contents are plotted in Appendix A, Figure A-13.

Moisture data do not indicate an infiltration event over the monitored period. Little-to-no change in moisture contents were observed at the 2.6-m (8.4-ft) depth (SVR-12-MB, Sensors 283 and 284).

Table 6-13. Activated Stainless Steel Investigation Focus Area working soil-moisture sensors, depths, data collection, temperature corrections, and monitored wetting events for Fiscal Year 2004.

Focus Area Cluster	Sensor Identification Number	Depth (ft)	Moisture Data	Temperature Correction Applied	Wetting Event
SVR-12-M	284	11.45	Yes, until June 2004	No	No
SVR-12-MB	281	4.3	Yes	No	No
SVR-12-MB	283	8.4	Yes	No	No

6.9.2 Direct-push Type B Tensiometer Monitoring

Three DPTs were installed in the Stainless Steel Investigation Focus Area (i.e., T1, T2, and T3). Table 6-14 lists the depth and monitoring results (e.g., soil-water potentials and moisture trend) for the DPTs in the Stainless Steel Investigation Focus Area. Tensiometers T1 and T2 were removed on May 20, 2004; they both indicated water potentials exceeded -100 cm, but neither provided equilibrated soil-water potential data. Data are presented in Appendix B, Figure B-21.

Table 6-14. Fiscal Year 2004 monitoring results for direct-push Type B tensiometer sensors installed in the Stainless Steel Investigation Focus Area.

Focus Area Cluster	Direct-push Type B Tensiometer	Depth (ft)	Water Potential (cm of water)	Water Potential Trend
SVR-12-1-T1	T1	3.6	<-100	Did not equilibrate[a]
SVR-12-1-T2	T2	8.4	<-100	Did not equilibrate[a]

a. “Did not equilibrate” = Water potential is less than indicated (dryer).

6.10 Activated Beryllium Investigation Focus Area (SVR 20)

Six neutron-activated beryllium reflector blocks from the INL Advanced Test Reactor were buried in SVR 20 in 1993. The blocks contain hydrogen gas and C-14, which form compounds that are mobile in both liquid and gas phases. All sensors installed in this cluster were removed to accommodate grouting in May 2004.

6.10.1 Soil-Moisture, Resistivity, and Temperature Monitoring

Three SMR sensors in the Activated Beryllium Focus Area collected moisture-content data for FY 2004 and are listed in Table 6-15. Moisture contents are plotted in Appendix A, Figure A-14. Moisture plots for these probes indicate little-to-no change in moisture contents. No data was collected from the 4.2- and 5.3-m (13.8- and 17.4-ft) depths during the spring snowmelt, but the upper (1.3-m [4.4-ft]) sensor did not record infiltration during that time period.

Table 6-15. Activated Beryllium Investigation Focus Area working soil-moisture sensors, depths, data collection, temperature corrections, and monitored wetting events for Fiscal Year 2004.

Focus Area Cluster	Probe Identification Number	Depth (ft)	Moisture Data	Temperature Correction Applied	Wetting Event
SVR-20	260	4.4	Yes, until May 2004	No	No
SVR-20	259	13.8	Yes, until May 2004	No	No
SVR-20	258	17.4	Yes, until May 2004	No	No

6.10.2 Direct-push Type B Tensiometer Monitoring

Three DPTs were installed in Cluster SVR-20. Two of the DPTs appear to have been working in FY 2004 (see Table 6-16). The 3.9-m (12.7-ft) depth indicates water potentials of -450 cm with a slight drying trend from October 2003 to March 2004 followed by wetting to -250 cm in September 2004. The 5-m (16.4-ft) depth tensiometer indicated a similar trend although muted with readings from -150 to -100 cm. It should be noted that the water potentials are higher (wetter) in the deeper sediments. These DPTs were decommissioned and abandoned in May 2004. Data are presented in Appendix B, Figure B-22.

Table 6-16. Fiscal Year 2004 monitoring results for the direct-push Type B tensiometer instrumentation installed in the Activated Beryllium Investigation Focus Area.

Focus Area Cluster	Direct-push Type B Tensiometer	Depth (ft)	Water Potential (cm of water)	Water Potential Trend
SVR-20	T2	12.7	-450 to -250	Steady to February, then wetting to September
SVR-20	T3	16.4	-150 to -100	Drying to November, then wetting to September

7. EVALUATION OF SENSORS FOR LONG-TERM MONITORING

Of the three types of vadose zone moisture monitoring being conducted at RWMC—advanced tensiometers in the deep vadose zone, perched water monitoring, and surficial sediment monitoring (SMRs and DPTs)—advanced tensiometers are preferred for long-term monitoring because they provide data year-round during both saturated and unsaturated conditions (Meyer et al. 2005). Advanced tensiometers characterize moisture movement in the basalt and interbeds. Perched water monitoring detects and records water levels (1) at the surficial sediment/basalt contact and (2) in deep perched water zones. Surficial sediments are monitored by SMRs and DPTs, as part of a larger group of drive probe sensors that monitor moisture in and around the waste. Data from all of these sensors are collected continuously using dataloggers. The applicability of using these sensors for long-term vadose zone monitoring in the SDA is briefly discussed in the following paragraphs:

1. Advanced tensiometer monitoring in the B-C interbed will indicate that remedial action is effective by providing the first indication of changing moisture trends in the deep vadose zone. Placed in laterally extensive sediment layers, advanced tensiometers obtain aerially representative data that include the influence of local recharge and the spreading areas. Site management, stakeholders, and regulators can use these data to show the general public that the site is being effectively managed. With reliable soil-water pressure data, cost-effective management practices can be evaluated.

   Advanced tensiometers are preferred for long-term monitoring for the following reasons:

   - They provide, within several years, data on the effectiveness of the cap.
   - They provide large scale and long-term data on the moisture below and adjacent to the SDA.
   - They provide direct measurements of the parameter (water potential), are reliable, and have serviceable and replaceable pressure sensors features required for long-term measurements.
   - Minimum servicing and maintenance ensure reproducible measurements.
   - Sensors are replaceable and thus can be operated for an indefinite time period. Thus, monitoring data can be obtained and maintained throughout the full life of the disposal site.

2. Perched water monitoring uses pressure transducers to measure the depth of water in perched water wells or to detect the presence of perched water at the surficial sediment basalt contact. The water levels in the perched water layers (above the B-C and C-D interbeds) can indicate changes in the infiltration patterns in the subsurface. Pressure transducers have the following characteristics:

   - Provide reliable data on water levels
   - Infrequent servicing is required
   - Detection requires presence of 2 to 3 in. of perched water.

3. Moisture in the surficial sediments is monitored by SMR and DPT sensors.

   SMRs are permanently-installed, solid-state instruments that provide estimates of water content by indirect measurement and have the following characteristics:

   - Require no servicing beyond ensuring they have good electrical connections

- Provide an indication of changes in water content in the waste and sediments over time
- Suitable for long-term monitoring
- Data from this model of SMR sensors appear to be affected by temperature fluctuations
- Downhole portions of the sensors cannot be serviced or repaired.

DPTs provide the same data as the advanced tensiometers, but were constructed to be placed in the waste. DPTs have the following characteristics:

- Provide direct measurements of water potential
- Required stringent design criteria and so the internal workings are complex
- Field sensor calibrations are limited (a complex procedure)
- Instruments can be serviced, but are unable to be repaired following installation
- Limited range of measurements (not able to measure the dry range)
- Less suitable for long-term monitoring than advanced tensiometers since they require intensive maintenance.

8. CONCLUSIONS

These findings suggest that the arena for aquifer protection from buried waste contaminants lies in surface water management practices. Deep vadose zone transport of contaminants is ultimately affected by the amount of infiltration in the surficial sediments. In years with little water, the deep subsurface dries out and little transport occurs (e.g., FY 2004). If the water is managed such that it is not allowed to infiltrate into the subsurface, deep transport of waste contaminants would be effectively prevented.

Advanced tensiometer data from the deep vadose zone indicate three water-potential trends: (1) decreasing (drying or drainage), (2) stable (water moving downward under steady flow conditions), and (3) increasing (wetting up). Long-term decreases in water potential (i.e., a drying trend) were noted in both sediments and basalts, primarily along the east–west center axis of the SDA, as shown in Figure 3-5. The largest overall decrease in water potentials occurred in the shallow A and B basalts and in the 34-m (110-ft; B-C) interbed. These depths appear to be responding to decreased infiltration from the diminished average annual precipitation for the last five years. In addition, two tensiometers indicate a drying trend into the C-D interbed. Of the 14 advanced tensiometers showing a drying trend, 12 are located inside the SDA, with only one located outside of the SDA.

Water-potential data from 14 of the advanced tensiometer locations indicate little-to-no change in water potential, suggesting steady-state drainage conditions existed at those locations. The steady water potentials indicate that the unsaturated hydraulic conductivity and vertical flux rates have remained nearly steady at these sites. Eight of these sites are located inside the SDA, while the remaining six are located outside of the SDA. Only two deep tensiometers located south and west of the SDA, in the B-C and C-D interbeds, respectively, showed gradual wetting trends over the monitoring period. At depths exceeding about 220 ft, the moisture movement in the vadose zone may be affected by lateral moisture flow from the spreading areas.

Combining data from the decreasing and steady water-potential sites indicates that the interior of the SDA is currently undergoing a moisture drainage cycle, presumably due to decreased long-term infiltration in response to the low precipitation. The exterior of the SDA appears to be either wetting to the west of the SDA or showing steady-state drainage. Data from wells installed in FY 2004 are not included in this discussion due to a combination of the short data-collection period and the time required to ensure the tensiometers have equilibrated with the surrounding media. Water-level data from the deep perched water wells inside the SDA indicate a large decrease in water level in one well and near-steady levels in two wells above the 34-m (110-ft) interbed. Perched water levels in two wells completed above the 73-m (240–ft) interbed show steady trends. Overall, the deep perched water-level trends agree with the advanced tensiometer data.

Infiltration into the surficial sediments occurred at six of the ten focus area locations in FY 2004, based on SMR and DPT data. Five of these events were detected in the upper 5 ft of the surficial sediments—one probe location in the Uranium/enriched Uranium Focus Area, one probe location in the Pit 6 High-plutonium Density Focus Area, and at two probe locations in the Moisture-Monitoring Network area. Infiltration occurred in the deeper portion of the surficial sediments at two locations in the Depleted Uranium Focus Area—the 3.7-m (12.0-ft) depth at Probe DU-14-M2 in the waste zone in the Depleted Uranium Focus Area and at the 4.6-m (15.2-ft) depth at Probe DU-14-M1 in sediment underlying the waste. The timing of the infiltration events varied from March through September 2004 for the shallow infiltration events to August and September at the two deeper infiltration locations in the Depleted Uranium Focus Area.

Most of the instruments in the surficial sediments that exhibited steady (flat) moisture trends in FY 2004 were located in or below the waste. This may reflect the lower than average yearly precipitation for 2004. Precipitation in these areas may not have been sufficient for a moisture event to move through the soil to the instrument depth, or the moisture may have been relocated to low areas.

At this time, obvious infiltration and drainage events, stable moisture trends, and long-term changes in moisture content (over several years) can be extracted from the SMR and DPT data. SMR plots that showed slowly increasing or decreasing moisture contents could not definitively be identified as infiltration or drainage, because of a lack of confidence in the temperature corrections. The lack of confidence in the temperature corrections decreases the accuracy of the measurements and confidence in subtle data trends.

The shallow perched water data corresponded with water potential and soil moisture data within the surficial sediments. Even though the area has sustained years of drought, the formation of shallow perched water was detected at the interface between surficial sediment and basalt at four locations in FY 2004. In response to drought conditions, the length and depth of perched water formation was diminished, as compared to past years. The formation of shallow perched water is episodic, localized, and has been associated with areas where surface water ponding has been observed historically. The deep perched water showed steady (level) trends at all of the sites with the exception of 9V (B-C interbed) where the datalogger recorded a water level decrease of about 2.7 m (8.9 ft), indicative of gravity drainage of perched water at this location.

Monitoring shows that the drought of the past five years has resulted in a measurable decrease in the amount of moisture in the geologic profile and the elimination of episodic pulses of water moving through the deep subsurface at these sites. Since a barrier cap would reduce infiltration and function as a localized "drought," placing a barrier cap over the SDA will reduce the movement of moisture and transport of contaminants. Continued monitoring will provide direct evidence of the effectiveness of the remedial action at the SDA.

9. SUMMARY

The RWMC is located in a low area where water entering the area infiltrates into the ground, is lost to evapotranspiration, or is routed away from RWMC. Water from snowmelt in the spring appears to have the greatest impact on infiltration, because the evaporative processes are low and much of the water infiltrates into the ground. Some of this water moves into contact with the buried waste and has the potential to leach and transport contaminants deeper into the vadose zone and, eventually, down to the Snake River Plain Aquifer.

The key to controlling infiltration and the subsequent transport of contaminants is to eliminate surface water ponding. This is best accomplished by building a permanent surface barrier over the entire SDA.

The vadose zone monitoring activities at the SDA have evolved to provide the necessary data to characterize moisture movement in the vadose zone. Portions of the subsurface have been and can be targeted to provide data indicative of moisture movement in the vadose zone. Water borne transport is the key way for contaminants to be moved toward the underlying Snake River Plain Aquifer. Groundwater becomes contaminated when water infiltrates at land surface, percolates through the buried waste, dissolves contaminants and migrates to the underlying groundwater. Because dry soil (i.e., soil with a low water potential) is nearly incapable of transporting water, the rate of transport of contaminants from disposal sites to groundwater can be minimized by lowering the soil-water potential throughout the site. It should be noted that this monitoring has been conducted during a period of drought and so the moisture regime during wet time frames has not been documented.

Permanently installed tensiometers and soil moisture probes are deployed for obtaining long-term soil-water data and to map areas with greater probability for contaminant transport. These instruments are used to define how dynamic water percolation is and to establish baseline data. The baseline data will be used as the reference from which the effectiveness of the overall site management program will be evaluated. For example, the barrier is effective if the soil-water potential beneath the modification decreases over time. With this information, regulators and stakeholders can decide whether further site improvements are needed.

The monitoring network—consisting of SMR, DPT, perched water, and advanced tensiometer monitoring in the shallow and deep subsurface—should remain part of the long-term monitoring strategy in the SDA. These data provide a monitoring reference and baseline data to help assess the remediation and future closure of the SDA. The monitoring provides invaluable information on what is occurring in the waste zone and deeper into the vadose zone; it is the first indication of changing conditions.

Waste zone monitoring provides the following:

- Supports development of post-OU 7-13/14 record of decision design requirements and systems
- Supports evaluation of uncertainty in the infiltration rates for the remedial investigation and baseline risk assessment model
- Provides a baseline for demonstrating effectiveness of a barrier cap and its long-term integrity.

10. RECOMMENDATIONS

Two major recommendations result from this report:

1. Continue to monitor moisture in the SDA—Monitoring should be continued because it shows the relationship of hydrology and flow-and-transport to changes in precipitation and climate. Understanding this relationship is critical to select the most effective remedial actions.

2. Integrate the monitoring efforts and focus these efforts toward long-term needs—Although the moisture monitoring was not initially an integrated effort, monitoring of surficial sediments and the deep vadose zone will achieve a complete picture of subsurface hydrology at the SDA. Such a complete picture will be necessary to determine how well the final remedial actions are succeeding.

The following paragraphs address specific recommendations for deep and shallow moisture-monitoring networks.

10.1 Deep Moisture-Monitoring Network

The advanced tensiometer network should continue to be monitored to document and quantify the large-scale picture of the deep moisture system at RWMC above the Snake River Plain Aquifer. Data collection from advanced tensiometers provides the baseline water-potential data from sedimentary interbeds and basalts that have been and are used for the hydrologic flow model calibration. Once remedial actions have been implemented for the SDA, these instruments will continue to produce data that will be used to assess the effectiveness of these actions and for predicting future impacts based on the response of the moisture system. Data acquired by the advanced tensiometers are also establishing baseline conditions that can be used to assess lateral flow from the spreading areas in the future.

Specific recommendations for the deep moisture-monitoring network include:

- Continue monitoring deep advanced tensiometers to determine subsurface response to diminished precipitation and infiltration and to discern the effects of lateral flow from the spreading areas to the SDA. In addition, monitoring is needed during normal and above-normal precipitation years, as well as during periods of discharge to the spreading areas. This continued monitoring is necessary to establish baseline conditions before emplacement of any infiltration-reducing cap at the SDA.

- Construct additional nested advanced tensiometer wells (multi-depth) to indicate vertical trends in water potential. Also expand the advanced tensiometer network to include wells instrumented with nested advanced tensiometers along the east–west axis of the SDA so that there is adequate spatial coverage to characterize the site.

- Incorporate the FY 2002 hydraulic property data into deep infiltration assessments and advanced tensiometer data evaluations. This will require development and documentation of representative moisture characteristic curves that incorporate these FY 2002 data.

- Analyze water-potential data to evaluate the timing and influence of barometric pressure changes on water potentials and to develop a method of removing that influence. This will improve the water-potential measurements to better discern small changes in infiltration and drainage at these locations.

- Perform laboratory and field tests to determine if those advanced tensiometers with very low water-potential measurements are in contact with bentonite or may be adjacent to dry media.

- Conduct ambient flux measurements to define the unsaturated hydraulic conductivity representative of ambient conditions. Because many sites have stable water potentials, accurate determination of hydraulic conductivity at the field water potentials should provide the best determination of steady-state flux.

- Lateral spread of water on the basalt may occur, especially when perched water develops. This is an area where further investigation could be performed by placement of sensors in the surficial sediment at multiple depths and distances adjacent to areas where surface water ponds.

10.2 Shallow Moisture-Monitoring Network

Monitoring in the surficial sediments should be evaluated to determine long-term needs and addition of instruments as required. These instruments should be located at the sediment-basalt contact (between the buried waste pits, trenches, and vaults) to provide data from these sediments. These data will provide the first confirmation that the remedial actions taken at this site are effective. Specific recommendations for the shallow moisture-monitoring network include the following:

- Evaluate spatial coverage of instruments in the surficial sediments in terms of meeting long-term needs. Monitoring in surficial sediments should focus on monitoring at the sediment-basalt contact. This can include replacing perched water transducers in neutron access tubes with advanced tensiometers or portable tensiometers to monitor either saturated or unsaturated conditions. These instruments should be in operation before remedial actions are implemented in order to establish a baseline of conditions.

- Determine if the SMR temperature corrections ensure the accuracy of the data. If so, obtain temperature corrections from the remainder of the probes. Evaluate the data from the SMRs over multiple years to determine if the temperature effects can be removed from the data.

- Install bentonite plugs around instrumentation casings to prevent water from flowing down the casing.

- Determine which DPTs should continue to be monitored based on data and long-term monitoring requirements. Calibrate the DPTs that are kept in operation. Analyze data regularly to enable timely servicing DPT instruments, as necessary.

- Collect snow measurement depths (effective water content) and map drift locations.

- Map the surficial ponding at the SDA from snowmelt in the winter and spring, including the lateral extent and depth. Record dates of ponding and photograph water accumulation of spring melt.

11. REFERENCES

56 FR 50634, 1991, "Sole Source Designation of the Eastern Snake River Plain Aquifer, Southern Idaho; Final Determination, U.S. Environmental Protection Agency," Federal Register.

Anderson, S. R. and B. D. Lewis, 1989, *Stratigraphy of the Unsaturated Zone at the Radioactive Waste Management Complex, Idaho National Engineering Laboratory, Idaho*, U.S. Geological Survey Water Resources Investigations Report 89-4065, U.S. Geological Survey.

Bishop, C. W., 1998, *Soil Moisture monitoring Results at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory, FY-96, FY-95, and FY-94*, INEEL/EXT-98-00941, Idaho National Engineering and Environmental Laboratory.

Bishop, C. W., 1994, *Expansion of Moisture monitoring Network at the Subsurface Disposal Area*, INEL-94/0144, Idaho National Engineering Laboratory.

Bowman, A. L., W. F. Downs, K. S. Moor, and B. F. Russell, 1984, *INEL Environmental Characterization Report 2*, EGG-NPR-6688, Rev. 0, Idaho National Engineering Laboratory.

Clawson, K. L., G. E. Start, and N. R. Ricks, 1989, *Climatography of the Idaho National Engineering Laboratory, 2nd Edition*, DOE/ID-12118, Rev. 0, U.S. Department of Energy Idaho Operations Office.

DOE-ID, 1991, *Federal Facility Agreement and Consent Order for the Idaho National Engineering Laboratory,* Administrative Record No. 1088-06-29-120, U.S. Department of Energy Operations Office; U.S. Environmental Protection Agency, Region 10; Idaho Department of Health and Welfare.

Dooley, Kirk and Brian D. Higgs, 2003, *End of Well Reports for the OU 7-13/14 Fiscal Year 2000 Well Drilling Project at the Radioactive Waste Management Complex*, INEEL/EXT-2000-00400, Rev. 0, Idaho National Engineering and Environmental Laboratory.

Holdren, K. Jean and Barbara J. Broomfield, 2003, *Second Revision to the Scope of Work for the Operable Unit 7-13/14 Waste Area Group 7 Comprehensive Remedial Investigation/Feasibility Study*, INEL-95/0253, Rev. 2, Idaho National Engineering and Environmental Laboratory.

Holdren, K. Jean, Bruce H. Becker, Nancy L. Hampton, L. Don Koeppen, Swen O. Magnuson, T. J. Meyer, Gail L. Olson, and A. Jeffrey Sondrup, 2002, *Ancillary Basis for Risk Analysis of the Subsurface Disposal Area*, INEEL/EXT-02-01125, Rev. 0, Idaho National Engineering and Environmental Laboratory.

Hubbell, J. M., 1995, *Perched Ground Water Monitoring at the Subsurface Disposal Area of the Radioactive Waste Management Complex*, *FY-1994*, INEL-95/149, Idaho National Engineering Laboratory.

Hubbell, J. M., 1993, *Perched Ground Water Monitoring in the Subsurface Disposal Area in the Radioactive Waste Management* Complex, FY-1993, ER&WM-EDF-002293, Idaho National Engineering Laboratory.

Hubbell, J. M., 1992, *Perched Water at the Radioactive Waste Management Complex*, VVED-ER-098, Idaho National Engineering Laboratory.

Hubbell, J. M., 1990, *Perched Ground Water at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory*, EGG-ER-8779, Idaho National Engineering Laboratory.

Hubbell, J. M., E. D. Mattson, J. B. Sisson, and D. L. McElroy, 2002, *Water Potential Response in a Fractured Basalt From Infiltration Events, Evaluation and Remediation of Low Permeability and Dual Porosity Environment*s, M. N. Sara and L. G. Everett, eds., ASTM STP 1415, American Society for Testing and Materials, West Conshohocken.

Hull, Larry C. and Carolyn W. Bishop, 2003, *Fate of Magnesium Chloride Brine Applied to Suppress Dust from Unpaved Roads at the INEEL Subsurface Disposal Area*, INEEL/EXT-01-01173, Rev. 0, Idaho National Engineering and Environmental Laboratory.

ICP, 2004, *End of Well Report for Waste Area Group 7 South 1898,* ICP/EXT-04-00206, Idaho National Engineering and Environmental Laboratory, Idaho Completion Project.

Irving, J. S., 1993, *Environmental Resource Document for the Idaho National Engineering Laboratory*, EGG-WMO-10279, Idaho National Engineering Laboratory.

Koeppen, L. Don, Gail L. Olson, Alva M. Parsons, Mitch A. Plummer, Paul D. Ritter, and A. Jeffrey Sondrup, 2005, *Fiscal Year 2004 OU 7-13/14 Environmental Monitoring Report for the Radioactive Waste Management Complex*, ICP/EXT-05-00795, Idaho National Laboratory, Idaho Cleanup Project.

Kuntz, M. A., B. Skipp, M. A. Lanphere, W. E. Scott, K. L. Pierce, G. B. Dalrymple, D. E. Champion, G. F. Embree, W. R. Page, L. A. Morgan, R. P. Smith, W. R. Hackett, and D. W. Rodgers, 1994, *Geologic Map of the Idaho National Engineering Laboratory and Adjoining Areas, Eastern Idaho, Miscellaneous Investigation Map, I-2330, 1:100,000 Scale*, U.S. Geological Survey.

Leecaster, Molly K., 2004, *Fiscal Year 2004 Geostatistical Modeling of Lithologic Characteristics in the Radioactive Waste Management Complex for OU 7-13/14*, ICP/EXT-04-00494, Idaho National Engineering and Environmental Laboratory, Idaho Completion Project.

McElroy, D. L., 1996, "Subsurface Disposal Area Perched Water Level Data Compilation," EDF-RWMC-901, Functional File Number INEL-96-226, Idaho National Engineering Laboratory.

McElroy, D. L., 1993, *Soil Moisture Monitoring Results at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory*, EGG-WM-11066, Idaho National Engineering Laboratory.

McElroy, D. L. and J. M. Hubbell, 2004a, "Evaluation of the Conceptual Flow Model for a Deep Vadose Zone System Using Advanced Tensiometers," *Vadose Zone Journal*, Vol. 3, pp. 170–182.

McElroy, D. L. and J. M. Hubbell, 2004b, *Advanced Tensiometer Monitoring Results from the Deep Vadose Zone at the Radioactive Waste Management Complex*, ICP/EXT-04-00241, Idaho National Engineering and Environmental Laboratory, Idaho Completion Project.

McElroy, D. L. and J. M. Hubbell, 2003, *Advanced Tensiometer Monitoring Results from the Deep Vadose Zone at the Radioactive Waste Management Complex*, INEEL/EXT-02-01276, Rev. 0, Idaho National Engineering and Environmental Laboratory.

Meyer, T. J., D. L. Anderson, C. W. Bishop, J. R. Giles, J. M. Hubbell, and R. L. Jones, 2005, *Final Report for the Waste Area Group 7 Probing Project*, ICP/EXT-05-00784, Rev. 0, Idaho National Laboratory, Idaho Cleanup Project.

Oberhansley, G. G., 2004, *Well Completion Report for OU 7-13/14 Vapor Port and Lysimeter Wells (RWMC-2004, RWMC-2005 and RWMC-2006) for Fiscal Year 2004*, ICP/EXT-04-00604, Idaho National Engineering and Environmental Laboratory, Idaho Completion Project.

Oberhansley, G. G. and J. M. Hubbell, 2004, *Well Completion Report for OU 7-13/14 Wells RWMC-1935 and RWMC-1936 Near the Radioactive Waste Management Complex for Fiscal Year 2004*, ICP/EXT-04-00624, Idaho National Engineering and Environmental Laboratory, Idaho Completion Project.

Salomon, H., 2004, *Field Sampling Plan for Monitoring Type B Probes for the Operable Unit 7- 13/14 Integrated Probing Project*, INEEL/EXT-2000-01435, Rev. 2, Idaho National Engineering and Environmental Laboratory, Idaho Completion Project.

Sisson, J. B., A. L. Schafer, and J. M. Hubbell, 2000, "Vadose Zone Monitoring System for Site Characterization and Transport Modeling," *Scientific Basis for Nuclear Waste Management XXIII*, ed. by Robert W. Smith and David W. Shoesmith, Material Research Society, Symposium Proceedings, Vol. 608, pp. 161–166.

Tullis, J. A., S. T. Marts, M. C. Pfeifer, and J. B. Sisson, 1993, *Corrosive Properties of Backfill Soils at the Radioactive Waste Management Complex*, EGG-GEO-10382, Idaho National Engineering Laboratory.

Vejvoda, Edward, 2005, *Summary of Rocky Flats Plant Waste Buried in the Subsurface Disposal Area*, ICP/EXT-04-00717, Idaho National Laboratory, Idaho Completion Project.

Wood, T. R. and A. H. Wylie, 1991, *Ground Water Characterization Plan for the Subsurface Disposal Area*, EGG-WM-9668, Rev. 0, Idaho National Engineering Laboratory.